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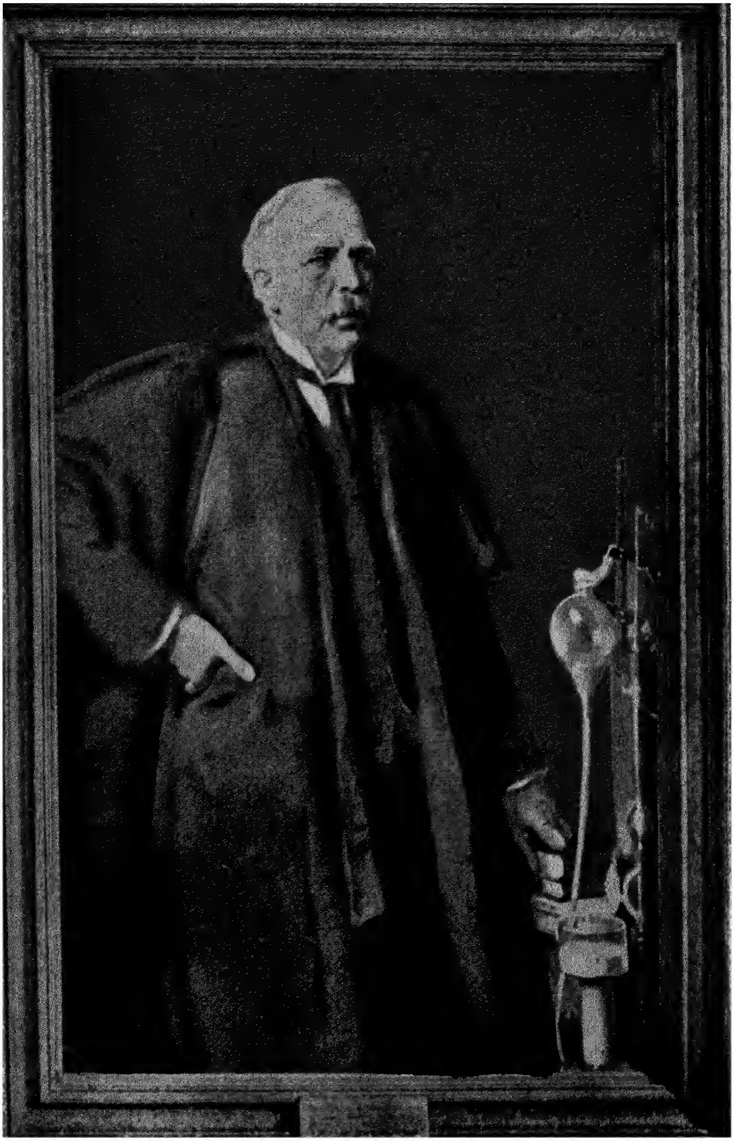

ERNEST, BARON RUTHERFORD OF NELSON, O.M., F.R.S.
From the portrait by Oswald Birley which hangs in the Royal Institution, London.
A replica was presented by Viscount Bledisloe to the New Zealand National Art Gallery.

MAN OF POWER

The Life Story of
Baron Rutherford of Nelson, O.M., F.R.S.

By

IVOR B. N. EVANS

With 11 Half-tone Illustrations

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TO

MY MOTHER

PREFACE

AT each critical stage in Britain's share of advancement in physical science a giant has arisen possessing the courage, initiative, and imagination to make the necessary revolutionary changes, against all opposition.

Bacon, Robert Boyle, Newton, Henry Cavendish, Dalton, Faraday, Joule, and Clerk Maxwell were such men. Now the name of the late Lord Rutherford is added to the list.

In this book I have endeavoured to outline Rutherford's scientific achievements, together with the story of the vast work he did in the interests of British industry and in the safeguarding of the freedom of knowledge against intolerance.

Rutherford possessed immense personality and force of character which is revealed in the story of his private life. That life, however, was bound intimately with science.

I have done my best to give a straightforward study of the greatest physicist of the twentieth century, without resorting to what F. L. Lucas terms an 'interiority complex.' Rutherford was too big a personality to be dealt with rashly and in such a manner.

If, on conclusion, the reader gains a general idea of Great Britain's leading part in the world of physical science and how much of it is due to New Zealand's greatest son, then I think that this small tribute to Rutherford's work will have justified itself.

To Mr. R. L. Hadfield I owe a great debt of gratitude for the time and trouble he has taken in assisting me in all ways with the manuscript. To Dr. W. M. Evans I am indebted for reading the proofs. My thanks are due to Mr. Walter Adams, Secretary of the London School of Economics, for his perusal of Chapter XXII when he was Secretary of the Society for the Protection of Science and Learning.

To Dr. F. Demuth of the Notgemeinschaft Deutscher

Wissenschaftler im Ausland; Professor E. J. Evans, University College, Swansea; Dr. A. S. Russell; Dr. F. A. B. Ward of the Science Museum, and to many other people who have assisted me in some way or another, I express my thanks.

The following journals have been of chief assistance to me: *The Proceedings of the Royal Society*, Section A; *The Philosophical Magazine; Nature; the Annual Reports of the British Association for the Advancement of Science; The Times* newspaper.

Finally, all those who have in any way written about Lord Rutherford.

IVOR B. N. EVANS.

LONDON.

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CHAPTER I

PIONEER DAYS IN NEW ZEALAND

IN the winter of 1842 a great storm lashed the Bay of Biscay into fury. Among the craft which fought the mountainous seas was the 300-ton sailing-ship—*Phœbe Dunbar*, out of Glasgow and bound for New Zealand. So fierce was the gale that the captain was forced to turn about and shelter in the Bristol Channel.

On board the *Phœbe Dunbar* were a number of Scottish emigrants, bent on seeking their fortunes in the distant lands that lay at the bottom of the world and which, they had been told, offered golden opportunities to the farmer and the pioneer.

Amongst these emigrants was a child barely three years old. If the *Phœbe Dunbar* had foundered in that storm, as near she must, and with her had gone that child, the world would have been robbed of one of the greatest scientists of all time. For the name of the child was James Rutherford, and thirty-two years later he was himself to have a son who was named Ernest.

Thus it was nearly a hundred years ago that the great scientist's grandfather left Perth with his wife and family, on the threshold of a great adventure. Their goal was the South Island of New Zealand, where the sturdy Scottish pioneer intended to turn his knowledge of timber and the saw-mill to good account.

The journey out to New Zealand gave the Rutherfords a foretaste of the hardships which the new life was to provide.

It was not till six and a half months after waving goodbye to the shores of Scotland that the passengers on board the *Phœbe Dunbar* saw the black line of the coast of New Zealand rise above the horizon.

The voyage of the *Phœbe Dunbar* was just another brick in

the building of the British Empire, a mighty epic that to-day is taken for granted.

Such an adventure as that on which the Rutherfords embarked in 1842 would find little favour with the modern generation. A man and wife decided to leave all that they knew, security and safety, friends and memories, and venture out on a journey that was to last for over half a year and lead them they knew not where. Six months on a 300-ton sailing-ship equipped without a vestige of luxury or comfort, six months of empty seas and wild uninhabited shores! They were saying 'Good-bye' to one life, 'Hail' to another. And the only tools with which they were to build this fortune of which they dreamed were strong hands, endless determination, and the will to work.

It was these qualities, derived from their virile Scottish ancestors of the Border, that were passed down from father to son and again from son to grandson, these qualities that enabled Ernest Rutherford to storm the heights of scientific achievement, to carry on doggedly when others gave in and, by sheer hard work, determination and character to place his name on the scroll of scientific heroes.

The first New Zealand home of the Rutherfords was Matucka. Here they set up a saw-mill, living for several years in a raupo hut in the heart of the dense forest.

In course of time they moved to West Waimea, near Brightwater, where a water-driven saw-mill was built, and though the conditions here were better than at Matucka they were still of the most primitive kind, the settlers having little beyond their own, unaided efforts to supply them with the elementary necessities of life. Conditions in South Island were crude, life was frugal, and only those who had the courage and determination to fight for existence night and day could hope to survive.

The Rutherford family worked at their saw-mill by day, felling trees, and grubbing out the stumps; at night they planted wheat, every grain of which had to be passed through the hands to cleanse it of rust.

Their harvests were reaped with the sickle, and the wheat was threshed with hand-flails. Then, that they might have flour for bread, the grain had to be carried on the back for four miles to a flour-mill.

The youngest of this family, James Rutherford, had been born in 1839 at Perth, and he was thus only three when he arrived in New Zealand. Schools were few and far between; the children of those who depended for their living on dwelling in the remote places grew up with little book-learning. James' parents gave him elementary instruction, but it was not until he was in his 'teens that he was able to attend a night-school and thus gain any education other than that imparted by Nature herself by close contact with the trees, the hills, and the rushing waters.

That pinning down to the soil, that ceaseless effort to snatch from the earth the simplest necessities of life, that lack of contact with the outer world, which habitation in the forests imposed, did not produce in any of the younger Rutherfords an atrophy of mind. The family was exceedingly hardy, but it was also progressive and venturesome, facing a daily grind the like of which has caused the failure of countless pioneers. Yet they sought further outlets for their energies.

Even to-day, in certain parts of New Zealand, children can attend school only by riding many miles on horseback, sometimes two or three to the horse, or, on the coasts, by crossing inlets and bays in boats. In those days international communications were more difficult, and an example of the remoteness of the Rutherford family from contact with the outer world exists in James' telling his children in after years that he celebrated the fall of Sebastopol six months and four days after the event.

In 1866 the family moved to Brightwater, where James married, his wife being Miss Martha Thomson, the daughter of New Zealand settlers from Sussex, who was in her own way also a pioneer, being the first woman school teacher in New Zealand. Shortly after the marriage James established the first flax-mill to be opened in the South Island.

On 30 August 1871 there occurred an event which gave James and Martha great pleasure. This was the birth of their fourth son, but it is unlikely that they thought for a moment that there had come into the world one whose name would in the fullness of time become known from one end of the world to the other, one who would make a mark in history so deep that his name would stand by the

side of those of such men as Faraday and Isaac Newton. The laws of gravity, the binomial theorem, the differential calculus, and the dynamo were to be equalled in importance by the work of the brain then brought into the world in a cottage 'midst the depths of the New Zealand forests.

The child was named Ernest, and though as soon as he was able to begin to learn he displayed an inquiring turn of mind, there was nothing about him to suggest what he was to become. Here was no youthful prodigy.

His early years were spent in the hard, active life that makes a settler's child rugged, hardy, and good at using both head and hands.

The cottage in which he was born was an unpretentious building of the frame type made familiar to us by pictures of American life in the wilder parts of the West. It was built of weather boards, boasted but few windows, and its steep gabled roof was covered with wooden tiles or 'shingles.' The ground in which it stood was surrounded by a simple cleft-wood fence.

This home would probably stand no chance of being passed by any English surveyor of to-day; it would be condemned as insanitary, lacking in the requisite number of cubic feet of air per person, and as having insufficient light; yet in it lived one of the sturdiest and happiest families of the many hundreds which were at that time building up the prosperity of New Zealand, facing hardships cheerfully and having unbounded faith in the future of their country.

Humble though the birthplace of Ernest Rutherford was, few boys would not delight in the surroundings. Beyond the flat country in which the settlers had placed their homes and started their farms were rolling foothills leading to magnificent mountains; of woods and rivers and opportunities for delightful wanderings, fishing, shooting, and climbing there were many.

Obviously chosen by those settlers on account of its sheltered position, its beauty, and its nearness to the sea, the district surrounding Brightwater formed the foundation of the island's prosperity. Set in a fertile, rolling plain of triangular shape, two sides being bounded by the mountains, the third open to the sea, the country through which Ernest Rutherford roamed as a young boy has the soft

contours and sweeping grassland of an English county, and his early impressions must have been constantly called to mind when later he came to reside in England. Save for the ring of mountains, rugged and snow-capped, the plain in which Brightwater stood is remarkably like Cambridgeshire and many parts of the home counties.

When Ernest was five years old the family moved to Pungarehu, in the province of Taranaki, where, at Foxhill, James started a farm and carried on his work of cultivating flax, of which industry he was a pioneer.

The way of the pioneer is seldom other than hard, and this venture was not accompanied by unbroken success. Floods and market vicissitudes often swept away what profit had been made, but James's work was highly skilled and he was already making a name for himself in the industry.

At this period in the history of New Zealand internal communications were difficult and a serious bar to overland commerce. Good coach roads were, however, being constructed, and the railways were making headway. About 1000 miles of the latter had been laid down, and the telegraph was beginning to link up the ports with outlying townships.

The railway construction that was being pressed on did James a good turn, for, never idle and ever seeking for means of adding to his resources, he, in 1877, took a contract with the Government to cut 40,000 railway sleepers, his earlier days at the saw-mill making him well acquainted with such work.

It was necessary for him to continue working hard, for his children now numbered twelve, and at the best of times the homestead was little more than a cottage. The cottage in which Ernest was born has been demolished, but before it disappeared Dr. Easterfield, of the Cawthorn Institute, had a photograph taken, that its appearance as the birthplace of one of the world's greatest men might be preserved for the interest of future generations.

In the meantime, Ernest was attending school at the State primary institution at Brightwater. The new school system had just been introduced. The Education Act of 1877 established these schools in which teaching was free, secular,

and compulsory for children between the ages of seven and thirteen. Grants for scholarships were also provided from primary to secondary schools and to Canterbury College, Otago University, and others. These grants were to play an important part in Ernest's life.

With its vigour and enthusiasm the new school system met the demands of a generation eager to receive instruction in the spirit in which it was given. It was not until many years later that the system became stereotyped and monotonous, thus losing much of its effectiveness and tending to become sterile.

From his earliest days at school Ernest Rutherford displayed a keen and active mind. Here was no son of the wild reluctantly picking up a little book-learning and impatient of the restraint imposed by a school ; he was as one who even in tender years had mapped out a course and, with a purpose beyond his years, intended to pursue every means to his end. While the average child takes lessons more or less as a painful necessity, Ernest Rutherford showed an intention of taking full advantage of the education New Zealand was now offering.

He was a hard worker and was capable of a degree of concentration which surprised his teachers ; he lapped up all they could give him, though as yet no idea that he would ever adopt an academic career had entered his head.

When he was eleven years old, that is, in the year 1882, the family moved to Havelock, in the province of Marlborough, and here Ernest Rutherford spent many happy years. He was fortunate in coming under the guidance of Mr. Jacob H. Reynolds, the classic master, who gave him a sound grounding in Latin, which was to prove of great use to him.

Ernest's active, versatile mind sought countless interests, and there are many stories of his boyish experiments with a diversity of subjects. Not unlike other boys of his age, he delighted to play with toy cannons and cameras, or to investigate the interior economy of clocks, but there was a purposefulness about his inquiries and a seriousness about the method of approach that spoke of things to come, and quick wit and nimble fingers mended where others would have destroyed, improved where others would have spoilt.

He made gunpowder and discharged marbles from toy cannon, working out a system of increasing their range; he took one of his father's clocks to pieces, but to the surprise of its owner restored the parts and improved its time-keeping. He became an enthusiastic photographer, having made a camera for himself, and it is recorded that not an inch of the surrounding country or a member of his family went unphotographed.

It is not surprising that he was keenly interested in the water-wheels which drove his father's saw-mill, and he proved himself a thoroughly capable workman when the need for helping in the repair or adjustment of the plant arose. Ernest also disclosed a passion for music, and he constantly asked his mother and other members of the family to play or sing.

He was a voracious reader, devouring the contents of any book on which he could lay his hands, one of his particular favourites being the works of Dickens, and he would roar with laughter over the adventures of Mr. Pickwick, in whose character there were traits very similar to those which Ernest himself was later to display.

When enumerating the qualities of a young boy of this type it is very easy to paint the picture of a prig. Ernest Rutherford was very far from being that; in all ways he disclosed the characteristics of a hardy, adventurous colonist. Well-built, exceedingly active, he was a typical young New Zealander of his day, and his pranks were as boyish as might be expected of one brought up in such surroundings. He was an adept at singlestick, which in those days was taught at all schools in New Zealand. Later his prowess proved very useful when, as librarian, he had to keep order at Nelson College. Birds'-nesting, spearing eels in the river, or catching trout in the pools in the valleys occupied his leisure hours.

During holidays he was often asked to teach his younger sisters, and though he was willing, the girls do not appear to have been so keen, for, when his mother asked him to give them lessons he invariably replied: "If they are mustered at nine o'clock, I will; but you must do the mustering." He kept them under restraint by tying their pigtails together!

It has since been remarked that this was a definite sign of the organizing ability which he was to develop later to the full.

Holidays were, however, often used as a means of adding to the family income, and on one occasion Ernest and his three brothers, Jim, Herbert, and Charlie, went hop-picking at Foxhill, earning about £13 in six weeks.

During this holiday Ernest very nearly lost his life. He and Jim went bathing in the Wai-iti River, a foolish thing to do, since neither could swim. Ernest got out of his depth and was in such grave difficulties that he would certainly have been drowned if Jim had not made a desperate effort to reach him. By a stroke of fortune he was just able to grasp Ernest's hand and drag him ashore. Neither of the boys said anything about this escapade at the time, for though they were both badly frightened they did not want bathing to be prohibited, as it certainly would have been had their parents learnt of Ernest's narrow escape.

One of Ernest's diversions was the shooting of pheasants and wild pigeons. He would be up before dawn and, riding horseback through the bush, would reach his hunting-ground just as the sun was rising, at which time pigeons flocked amongst the miro trees, being attracted in large numbers by the berries.

These trees are high, and at first Ernest found his sport exceedingly poor owing to his possessing an inferior gun and ammunition. Moreover, the small target offered by the birds made them very difficult to hit even with a good gun and cartridges. Eventually Ernest hit on the idea of always firing just at the moment when they were about to alight, their wings being then fully spread. This method proved highly successful, and on one occasion he claimed a bag of sixteen birds.

Many years later Ernest Rutherford was to shoot at a very much smaller target with the finest ammunition in the world and score direct hits, when he bombarded the atomic nucleus with alpha-particles.

Of a happy and lovable disposition, Ernest was always eager to help his parents. During his hours out of school he would turn his hand to anything to help his father, from painting a shed to looking after the rope-walk in the flax-mill.

Both in school and out he displayed a prodigious energy, working hard and playing hard, and attacking anything he had to do with a penetrating intelligence which delighted his father and his teachers. The conditions of his everyday life, the burning of a pioneering spirit, and the problems which continually faced the New Zealander of that time allied together in forming his character, which ever displayed the spirit of adventure.

Though the settlers of that time were engaged in agricultural pursuits, most of them were highly intellectual. Thus Ernest Rutherford's youth was passed amongst men whose characters were moulded by the problems they faced in the struggle for existence, but who realized the importance of education and culture and did everything they could to encourage a love of learning in their children. In their discussions Rutherford had the opportunity of expressing his ideas.

At school Ernest's abilities were quickly realized, and his masters wisely allowed him to pursue his own lines of thought, to use his own ways of expressing his ideas, and to reach his conclusions in his own way. A keen, active, and original mind was the result.

The grounding in Latin given him by Mr. Reynolds had a happy result and was, in one way, the first step upwards towards the heights taken by Ernest Rutherford. It was instrumental in his winning an Education Board Scholarship while at Havelock School, which gave him the privilege of attending Nelson College as a boarder. He was, in fact, so far advanced in his work that in 1887, at the age of sixteen, when he arrived at Nelson College, he went straight into the Fifth Form.

Here he became a firm friend of Mr. Littlejohn, the science and mathematics master, and to him he owed much of his grounding in physics and mathematics. It so happened that he and the master were thrown together a great deal during their work at Nelson College. Science was amongst the optional subjects, those who did not take it having to take French. The majority took the former, and as a result Ernest was often a class by himself, doing physics and chemistry alone with Mr. Littlejohn.

He and the master spent many of their leisure hours

together, and they were often to be seen discussing a scientific problem in Hamden Street and drawing diagrams in the dust. Mr. Littlejohn later became headmaster of Scots College, Melbourne.

Ernest entered into all the usual activities of school life at Nelson, and though he never professed to be an athlete, he was a keen rugby player and was a forward for the first fifteen during this last year at Nelson College.

It was noted both by masters and pupils at this time that Ernest possessed remarkable powers of concentration. Not only could he study in comfort in the midst of loud turmoils, but it was said that when deep in any problem he could be struck on the head with a book without noticing it.

On one or two occasions he did notice it, and being a powerful lad and quite capable of looking after himself, he dealt with the jokers according to their deserts.

Ernest swept up prizes, taking the examinations in his stride. At Nelson College he won all the mathematical prizes in his class, the Stafford Scholarship for History, the Senior English Literature Scholarship, the French Scholarship, the Simmons prize for English Literature, and the classical and Latin prizes in the Sixth Form.

Then there occurred the event which was the starting-point of his scientific career. He had sat for the Junior University Scholarship at Canterbury College in 1889, and was staying with his parents during the holidays at Pungarehu whilst waiting to know the result.

One morning he was digging potatoes in the garden, when his mother came running out to him in an excited manner.

"You have won it," she cried.

"Won what?" asked Ernest, and then realizing that his mother meant the scholarship, he threw down his spade, and said:

"That is the last potato I shall ever dig."

He was often heard to remark in later life that but for this scholarship he would probably have been a farmer. The world would have lost thereby a great scientist and would have been all the poorer, but there is no doubt that New Zealand would have gained a remarkably well-run farm.

CHAPTER II

STUDENT DAYS AT CANTERBURY

WHEN Rutherford entered Canterbury College he attracted no particular attention at first. It is true that he went with an excellent reputation for application and with a list of minor successes to his credit, but amongst the students at the College there were many with records as good, and there was no reason why Rutherford's arrival should be specially noted.

His contemporaries found him frank, boyish, simple in his manners, very likeable, but without any sign of precocious genius. Though studious and hard-working, he took an interest in all the usual College activities. Besides his interest in rugger, he took up boating and tennis. Dancing was popular at the College, but Rutherford took no interest in it, it is said, because he had no dress-suit. This may have been the reason, since funds were none too plentiful, but it is more likely that Rutherford saw in dancing a way of wasting valuable time, although he was by no means an unsociable person.

Rutherford had a great love for outdoor sports which he considered essential to the maintenance of the mental and physical fitness required for the concentration of mind needed in his scientific studies and also for the application necessary to his research work. He considered that physical fitness was very important if one wished to be mentally alert and, in fact, early realized that mental and physical activity are partners.

At the time of his entry, Canterbury College, New Zealand—the then very young Hall of Learning at the other end of the world—was quite a small institution. It boasted only seven professors and one hundred and fifty regular students. There was nothing at all palatial about its build-

ings or luxurious about its fittings. The physics laboratory consisted of a galvanized iron building about sixty feet long and incorporated the chemistry laboratory, the building and its contents being in striking comparison with the amenities provided for students in more modern colleges throughout the world. None the less, it was to produce one of the greatest scientists of this or any age.

The two professors with whom Rutherford came most closely into contact were Professor A. W. Bickerton and Professor G. H. H. Cook, the former having charge of the physics laboratory, the latter teaching mathematics. The two men were strangely dissimilar in character and outlook.

Professor Bickerton was 'heterodox' in all his views, inclined to be erratic in his methods, but having the saving grace of originality. He was, however, a man eminently suited to teach young Rutherford. They understood each other from the start, and the originality in Bickerton, which led Rutherford away from the hidebound physical science of the day, fitted in admirably with the searching, querying disposition of his student. Professor Bickerton, besides being a man of independent thought, was of great mental energy, and it was he who evolved and propounded to the end of his days an astronomical theory of partial impact.

When Professor Bickerton died in January 1929 at the grand old age of eighty-seven Rutherford wrote[1]:

'... As a lecturer he was unusually clear and stimulating, and his obvious enthusiasm for his subject communicated itself to his classes. He took a personal interest in his students and their work, and was always active in encouraging original investigations of whatever kind. His power of popular exposition, his enthusiasm and versatility were of great value in promoting an interest in science in a young community.

'... And he had friends amongst all classes of the community. He was, indeed, a most lovable character.'

On the other hand, Professor Cook was strictly scholastic in his views and methods. Within his limitations he was a very able man and capable of giving a solid foundation to his pupils. All that he taught Rutherford was sound, and

[1] *The Times*, 24 January 1929.

he acted as a stabilizing influence on the wilder flights of his colleague, Professor Bickerton, and under whom Rutherford showed early in his training a magnificent power of experimentation.

Rutherford is described at this juncture as being 'conservative in manner but very fond of discussion.' Many of his fellow-students remember vividly the tremendous discussions which took place during moonlight walks over the Port Hills, when, as is usual amongst students, every subject under the sun as well as the moon would be eagerly taken up. Arguments were furious, and far into the night Rutherford's voice could be heard above the others, in hot debate. The writings and personalities of such people as Tennyson and George Sand, who were then very much in vogue, came in for much intelligent discussion and criticism.

Rutherford was also a keen member of the Debating Society, and further opportunity came to him with the establishment of the Science Society in 1891. The first subject chosen was 'The Evolution of the Elements,' indicating that Rutherford even at this time was already considering the possibility of sub-atomic structure; but he jibbed at the word 'evolution.'

In those days evolution was not considered a respectable belief, and though it was discussed, the University community felt shocked, and Rutherford himself thought that things were going too far. On this account it was with some difficulty that he was persuaded by his friends to take the secretaryship of the Society in 1893.

That year was a milestone in Rutherford's career, for it was then that he graduated as a Bachelor of Arts and at the same time gained a senior scholarship in mathematics.

He then began to prepare for his Master of Arts degree, and to do so it was necessary for him to deliver a thesis on original research work.

While he was preparing his thesis, Rutherford taught at the Boys' High School, Christchurch, and it is amusing to record that he was probably one of the worst schoolmasters ever to draw on a blackboard.

For many days after his departure he remained a delightful memory to his pupils, for his ideas on discipline were so nebulous as to be almost non-existent. Disorder seems to

have been the order of the day, and he appears to have been quite incapable of attuning himself to the needs of the younger mind. His own mental processes were so rapid that he failed to appreciate the necessity of going slowly with young boys, and he was either astounded or wrathful that his lightning-like trains of thought had not been followed.

When, during a period of uproar, he noted any particularly noisy boy he would sternly send that boy to fetch the 'Appearing Book,' in which was to be written down the name of the culprit for detention after school. It was soon discovered, however, that all the boy had to do was to stay out of the class-room long enough for Rutherford to have forgotten all about the incident, then sneak back and take his place quietly. In the meantime, Rutherford had gone on to something else, and the culprit almost invariably escaped further notice.

Rutherford was ahead of his time in allowing the pupils to have the answer-book or key to mathematical problems, the modern idea being that one or two problems worked out right are better than any amount worked out wrong, the pupil being able to check his results with the key. But Rutherford had not had enough experience as a schoolmaster to learn that the ways of the schoolboy are legion and his cunning unbeatable even by the heathen Chinee. Imagining that the young rascals were interested in producing good work, he allowed them too much latitude and rarely, if ever, inspected the working out of problems. Many of his pupils got good marks for problems in algebra, for instance, in which the result was correct, the body consisting of a mere mass of x's and y's which had a purely decorative effect.

The boys summed him up as a genial person totally uninterested in the matter of keeping order, and though he would often flare up into anger, these outbursts were followed by periods of desperate calm during which so little work had to be done that the latter moods were hailed with the utmost joy.

While the pupils appear to have been happy during these days, Rutherford was no less so ; in fact, during the whole of his stay in Christchurch he found life thoroughly enjoyable and derived mental stimulus from the contacts he made both

at the college and in the town itself. This always go-ahead town was then full of new ideas and new movements, social, political, and philosophical.

During Rutherford's studies at this period he became particularly interested in the work of the scientist and physicist, Heinrich Rudolf Hertz. In 1880, while assistant to Helmhotz at the Berlin Institute, Hertz carried out a series of researches on electric discharges in gases, and in 1885 at Karlsruhe he began to study electro-magnetic or radio waves.

Hertz's experiments aroused the enthusiasm of Rutherford, and he began of his own accord a similar series of experimental investigations. Knowledge concerning radio waves then was very rudimentary, and although methods for generating the waves had been devised, there was no satisfactory means of detecting them. A scientist, Branley, had already invented a coherer, but the instrument was erratic and unreliable. Rutherford therefore set himself the task of developing a new method of detection.

This work was not carried out in the most ideal of circumstances. Those students and research workers who have been provided by the bounty of men such as Rockefeller and Lord Austin with building and apparatus costing many thousands of pounds and providing every conceivable requirement would shudder at the crudeness and discomfort of the laboratory in which Rutherford worked, and the apparatus at his disposal.

His work was carried out in what may now be called a 'Nursery of Genius' known at the time as the 'den.' This den was an underground room beneath the physics laboratory in which the students hung their gowns. It still exists, though the building which formerly stood above it has passed away, and it has been suggested that a plaque should be placed over the door calling attention to the important part this little room has played in the history of science.

Here Rutherford worked on his researches into radio waves, assisted by Professor Bickerton and Mr. S. Page, the demonstrator, and his materials were on a par with his surroundings, yet they were productive of results carried out with such skill that the measurements were of a very minute order indeed for those days. They were destined to

contribute much to the history of investigation into radio waves. Rutherford had to build his own instruments, and he spent long hours constructing the detector which he sought, his figure passing in and out of the 'den' being a familiar sight as through his vacations he spent many hours on his ideas, which were, in many cases, revolutionary. This work forged the key that opened up the way which led him to the world of fame.

Rutherford's detector was constructed from fine sewing needles. At last there came a day when in the presence of the students and professors he transmitted a wireless message through the old iron laboratory building. The significant and triumphant occasion was probably the first on which wireless telegraphy was ever demonstrated in New Zealand. Thus he showed that high-frequency currents from a small Tesla coil, of 100 million cycles per second, would strongly magnetize iron, contrary to the belief of the day.

As so often happens in the world of research, another man, some years earlier, had been working on much the same lines to the same end. He was the American physicist, Joseph Henry, who died in 1878. In 1842 he discovered that the discharge of a Leyden jar induced discharges in other circuits some distance away, this being a fundamental discovery of wireless telegraphy. The electric unit of self-induction is named after him.

Both Henry and Rutherford used an aerial, a coil of many turns round a bundle of fine sewing needles, and a small magnet which was deflected by the changed magnetism of the needles due to the current in the aerial produced by the wireless waves, but while Henry detected lightning flashes of several millions of volts up to a distance of ten miles, Rutherford succeeded in detecting the sparks from an induction coil with a voltage of only a few thousands at a distance of two miles.

The similarity of the two men's lines of research is remarkable, and in the course of a conversation in later years Rutherford was asked if, at the time of his experiments at Christchurch, he had already heard what Henry was doing. Rutherford replied: "No!"

The results of his experiments were communicated in two papers, the first was entitled 'Magnetisation of Iron by High-

frequency Discharges,' read to the College Scientific Society in 1894. The minute book of the Society records: 'The paper was very fully illustrated by experiments performed by Mr. Rutherford . . . the most striking being a reproduction on a small scale of Tesla's experiments on rapidly alternating currents.'

The second paper was published in 1896 in the *Transactions of the New Zealand Institute* and was entitled 'Magnetic Viscosity.' Among the results presented in this paper was the fact that Rutherford had been able to send waves down the 60 feet shed and through walls and detect them at the other end.

In 1894 Rutherford obtained the highest academic honours possible in Canterbury College. He was made a Master of Arts with double first-class honours in mathematics and physics.

This led to the second stride forward in his career towards world fame, for as a reward for his achievements the Commissioners of the 1851 Exhibition awarded him a scholarship which enabled him to leave New Zealand and enter the Cavendish Laboratory, Cambridge, where Sir J. J. Thomson was conducting his own famous experiments into the construction and mutation of the atom.

Rutherford left New Zealand in 1895, but though he was now to enter a laboratory which he was eventually to direct himself, for nineteen years, and make even more famous than ever with his great discoveries in atomic physics, he never lost his interest in his old University in New Zealand.

Rutherford delighted to attend gatherings of New Zealand graduates in London, presided at their dinners, and offered them frequent hospitality in his own home.

CHAPTER III

A CAMBRIDGE INTERLUDE

'In order to form a just idea of the relative importance of the work of different scientific men, it is essential not only to estimate the intrinsic value of their individual achievements, but also to take into account the prevalent ideas and the state of the laboratory technique in their sciences in the period under consideration.'

PHILIP LENARD.

IT is a strange coincidence that the year 1871, which saw the birth of Ernest Rutherford, was destined to see the foundation of the greatest experimental physical laboratory in the world, a centre which in the fullness of time was to be the scene of much brilliant work on the part of the young scientist.

In the year 1871 James Clerk Maxwell was summoned from retirement on his estate at Glenlair, Kirkcudbrightshire, to become the first holder of the newly formed professorship of Experimental Physics at Cambridge.

The Duke of Devonshire, then Chancellor of the University, had decided to found a laboratory at Trinity College for research in physics, and having endowed it well, he prevailed on Clerk Maxwell to superintend its formation and gather together what was ultimately a fine collection of apparatus. The laboratory, over which Maxwell was to reign until his death in 1879, was named the Cavendish (that being the name of the Devonshire family), in memory of the brilliant and eccentric scientist, Henry Cavendish. Maxwell established the tradition of the Cavendish, which was to be so brilliantly carried on by many others including Ernest Rutherford. Round him he collected a small circle of half a dozen brilliant students and with their help he completed

the first great step towards the discovery of the true nature of electrical phenomena.

In 1879, Maxwell, the keenest theorist and daring experimentalist of his time, died, and his place was taken by another very great experimentalist and mathematician, Lord Rayleigh, who carried on the tradition of Maxwell nobly until he retired in 1884.

He was asked to name his successor, and the choice he made created something like a disturbance amongst the older members of the academic staff of Cambridge, for he immediately nominated his most gifted pupil, Joseph John Thomson, who was then only twenty-eight years old. Rarely, if ever, had one so young held a post of such eminence and responsibility, and as an example of the effect caused by Lord Rayleigh's choice it is said that one great scientist went back to America, frightened at the prospect of having as professor one who was only two years his senior.

However, Lord Kelvin, Sir Gabriel Stokes, and Professor Howard Darwin decided that in Thomson there existed one with the clear imagination and powerful, penetrating mind necessary to the position, and Lord Rayleigh's nomination stood. Thus, Joseph John Thomson (now Sir J. J. Thomson, O.M., Master of Trinity College) became the third Cavendish Professor of Experimental Physics.

It is first necessary to consider the work which Thomson carried out before the arrival of Rutherford, for this work acted as the stepping-stones upon which the young man from New Zealand was to make his way forward.

Thomson had interested himself in research on the atom, and at the age of twenty-five had won the Adams Prize for an essay in which he had attacked as unscientific the theory that atoms were whirlpools or vortices in the ether. When he came to fill the chair at the Cavendish Laboratory he chose to research in the realms of electricity, for he was convinced that in discharges of high voltages through gases lay the key to the secret of the mystery of the material world.

Some years before Crookes had found that on passing a high voltage through a partially evacuated tube a peculiar light appeared in the region of the negative plate or cathode. Thomson decided to investigate this, and he found that the light beams, or cathode rays as they are now called, were

bent by the field of a magnet. Thomson carried out experiment after experiment on these rays, using various intensities of electricity at low pressures of evacuation until he had amassed a formidable pile of facts and figures.

In 1894 he went to America and lectured on 'Electrical Discharges through Matter'; he showed that he was evolving a new theory, not as a creed, but as a guide to work to a further end.

Then came the announcement which startled the whole scientific world and upset the firm beliefs of decades, an announcement of a discovery which was to revolutionize all our ideas on the substance of matter. On Friday evening, 30 April 1897, he announced that he had come to the end of twenty years' work. "Cathode rays," he said, "were particles of negative electricity"; he thus announced the existence of the electron, which, in place of the atom, was now the smallest known particle of matter, being a two-thousandth of the mass of hydrogen, the lightest element known. The electron was the 'fourth state' of matter, being neither liquid, solid, nor gas.

By 1895 Thomson had surrounded himself with a select group which had to be kept small through lack of facilities. It was composed of William H. Bragg (now Sir William Bragg, Director of the Royal Institution), Richard T. Glazebrook, who became Sir Richard Glazebrook, Director of the National Physical Laboratory, William Napier Shaw, now famous as a meteorologist; Harry F. Field, the famous geologist of Johns Hopkins University; and the great physicist, Arthur Schuster, later Sir Arthur Schuster, President of the British Association in 1915.

Thomson decided to open his doors to other research students; there was new ground to be explored. A new regulation was made that graduates of other universities were eligible for admission to Cambridge as research students, and that after two years' residence they should be eligible for the B.A. degree.

In 1895 there occurred two events of tremendous importance to the realm of science; they were Röntgen's chance discovery of X-rays and Rutherford's entry to Cambridge. Rutherford could not have arrived at a more opportune moment.

CANTERBURY COLLEGE, CHRISTCHURCH, NEW ZEALAND

By courtesy of the High Commissioner for New Zealand

Rutherford was the first student to apply under the new regulations. It happened that he was followed an hour or so later by the Irishman, J. S. Townsend, who has since become Wykeham Professor of Physics at Oxford. In this way the two new research students under the new regulation were destined to become professors of physics at Cambridge and Oxford respectively.

Rutherford had come to Cambridge for two reasons. Firstly, he had heard that it was there, in the Cavendish Laboratory, that pure science was most revered and the greatest researches in physics were being carried out; secondly, because the head of the department was J. J. Thomson, who, in the company of such men as C. T. R. Wilson and H. A. Wilson, was carrying out momentous researches in the electrical structure of matter.

The atmosphere of the Cavendish Laboratory was unique. It was highly charged with enthusiasm, emanating from men gathered from all parts of the world. There were honours students from the universities, sons of famous families and men who had begun life in a garret. From the London suburbs and from the distant parts of the Empire they came to carry on the never-ending fights for the secrets of science.

When Rutherford first came under the shadow of Trinity College, the shrine of Newton and Clerk Maxwell, he was looked upon as a novelty, and there was a tendency in some quarters to ridicule the young physicist from the Antipodes. Rutherford was not at all worried by this. The formidable questions he put were soon being received with something akin to awe; there was realization that the young New Zealander possessed a brain of unusual power. Rumour spread that there was 'a young rabbit from New Zealand who burrows very deep.'

Rutherford very quickly attuned himself to the spirit of Sir Joseph John Thomson, or 'J. J.,' as he was known to the students. J. J. was exceedingly human and inspiring, and helpful to all around him. He possessed a charming smile and was delightful to work under. Rutherford fell under the spell of this powerful intellect and soon joined in the informal tea-parties which Thomson held in his room nearly every afternoon. There science was the main topic,

but the cosmopolitan collection of students attacked every conceivable subject. Political discussions of an animated kind frequently took place. There was plenty of laboratory gossip and tall stories. It was remarked that it had to be a very tall story that J.J. could not cap with a taller. Rutherford found that he had entered into an amazingly happy life and a free and delightful comradeship.

While Rutherford was summing up his colleagues and making friends, they were taking stock of him, and it was one of his greatest gifts, his extraordinary energy, that made the first deepest impression. A contemporary described him by saying that he gave the impression not so much of being clever, but of possessing greatness. His intellectual machinery was not dazzling ; he did not appear to be subtle ; but his intense enthusiasm made his colleagues feel that his intellect was brilliantly illuminated with a tremendous inner light. They were startled, it was said, by the illumination of the ideas in his mind.

Some forty years later Rutherford, in the Norman Lockyer Lecture, compared the resources of the Cavendish Laboratory at this period with those of to-day.

He referred to the great advantages that had accrued to scientific research after the invention of an efficient form of electrical accumulator. The hours spent in the early days in preparing the messy wet batteries known as Grove's cells were recalled by him. These cells ran down very rapidly, and many valuable hours were wasted in their re-preparation. The modern accumulator, he said, had stopped all that.

The electrical apparatus was very crude. Much of the apparatus was home-made, from all kinds of odds and ends, and this earned for the laboratory the name of the 'String and Sealing-Wax' laboratory.

To-day the electrical researcher has dozens of delicate and portable measuring instruments available and accurate measurements that required hours to obtain in the old days are now obtained in a few minutes.

The most delicate instrument that Rutherford used in his work was invented over a hundred years ago. But for modifications introduced by C. T. R. Wilson it remains in its original simple form of two pieces of gold-leaf at the

end of a metal rod and enclosed in a glass case to shield the delicate foils from draughts.

In J. J. Thomson's days hours of pumping with complicated apparatus was required before his experimental tubes were sufficiently evacuated. To-day it takes just a few minutes to reach an almost absolute vacuum.

Rutherford was still very interested in his magnetic detector of wireless waves. His first work at the Cavendish was to improve its sensitiveness. It was at this work that he showed his exceptional driving power and organizing ability.

To test the detector it was necessary to take observations at two places simultaneously, while the transport of the instrument was a matter of some difficulty. He surmounted the obstacles in his way with the assistance of friends, and at one time he held the record for long-distance wireless transmission in England, having observed signals from the laboratory at a distance of two miles.

On 18 June 1896 his first paper was read to the Royal Society by J. J. Thomson. This gave an account of Rutherford's wireless researches, and was entitled, 'The Magnetization of Iron by High-frequency discharges and the investigation of the effect on Short Steel Needles.'[1]

It dealt with the detection of wireless waves whose source was half a mile from the detector.

The detector was extremely simple, and the *Encyclopedia Britannica* of 1902 described it thus :

'A very efficient detector, indeed by far the simplest and best for metrical work, is that invented by Rutherford . . . it is very delicate, though in this respect does not equal the coherer ; Rutherford in 1895 got indications when the vibrator was three-quarters of a mile away and the waves had to traverse a *thickly populated part* of Cambridge.' (Author's italics.)

Rutherford made the coil and core of his detector with excellent practical skill. The needles composing the core were 1 cm. long and only seven-hundredths of a millimetre in diameter, while the coil consisted of 80 turns of fine insulated wire whose total length was only 6 inches !

Rutherford did not carry out any further researches into

[1] Royal Society, Phil., Trans., A. vol. 198, p. 1 (1897).

wireless waves. He was satisfied that he had completed the work he had started in New Zealand, and he immediately turned his attention elsewhere. That is not to say that he lost all interest in wireless investigation. Though he personally continued no further work in this direction, he watched carefully all the developments and early realized the great value of the researches on the ionized layers of the upper atmosphere.

When he became head of the Cavendish Laboratory he had Professor Appleton under him as a research student and later as a staff colleague in the University. Appleton is to-day one of the greatest world authorities on wireless.

It was fortunate for the future pioneers of wireless that Rutherford decided not to pursue further research. Had he continued he would have been a very serious rival to them. Once the problem he had set his mind on was solved he dropped all interest in it and gave all he had discovered freely to the world. Rutherford was not interested in the commercial possibilities of his work.

The needles required remagnetization after the receipt of a signal which made continuous work with them arduous. However, Marconi overcame this by the evolution of an endless steel band passing through a 'washout' magnet. Marconi's development of Rutherford's principle, until the adoption of the wireless valve, played as large a part as other kinds of detectors in the development of wireless telegraphy.

Rutherford now plunged into the new research which was to open up one of the greatest and most important fields in the history of science.

Thomson was measuring electron charges, and Rutherford naturally became drawn into the work by the fact that while engaged on his wireless researches, X-rays had been discovered.

Gases are the simplest and most instructive phenomena of Nature. John Dalton, who had evolved an atomic theory and published a list of atomic weights in 1808, derived his fundamental laws of chemistry from experiments on gases, which are freely moving molecules like snooker balls, free from the complications possessed by solids and liquids.

When electricity is passed through a tube containing a

gas, it does not, like a metal wire, obey Ohm's Law, according to which the amount of current passing is proportional to the voltage. Instead an increase in the voltage did not increase the amount of current until a point was reached, when the gas ionized, that is, split into particles carrying positive and negative charges of electricity.

The discovery of X-rays solved many of the difficulties encountered by Thomson and gave scientific workers an extremely useful and powerful weapon. For ten years J. J. Thomson found that observations of the passage of electricity through gases were exceedingly difficult because of the high voltage required which resulted in the apparatus becoming hot. Flames were produced, and the voltage was so high that sparks were caused to pass, while the phenomena were so capricious in their behaviour that accurate observations were difficult to obtain.

X-rays altered all that, and it was found that under their influence a gas ionized immediately and that the smallest voltage could be passed easily. Rutherford was attracted by these newly discovered rays, and in 1896 he published a paper with J. J. Thomson on a method of preparing electrified air by means of X-rays; the air thus obtained could be blown down a glass tube several yards long without losing its conductivity. Rutherford devised several ingenious methods for examining the results.

He and J. J. Thomson found that the gas kept its conductivity for some time after the rays had ceased 'activating,' as exposure by them is called. The accuracy of observation and of measurement made possible by the X-rays resulted in research becoming much easier and more speedy, and Rutherford had the opportunity of displaying his powers of undertaking delicate experiments, which made the study of conductivity of gases metrical, whereas before it had been only descriptive.

Work was now started on the life of an activated gas. Rutherford and Thomson found that if the gas was blown through tightly packed cotton-wool, it lost its conductivity, as it also did when blown through metal tubes. Moreover, the smaller the bore of the tube, the more rapid was the loss of conductivity, and they came to the conclusion that 'something' had been removed.

When Rutherford and Thomson applied an electric field to a gas that was conducting electricity they found that the plates of the condenser gradually lost their charges.

This meant that there was something moving in the gas. Since, however, the gas is neither positively nor negatively charged with electricity it was assumed that the 'something' consisted of positively and negatively charged particles in equal quantities. These particles were called 'ions.' The negative ion was identified as the electron, and soon its mass and charge were determined. The positively charged particle gave rise to many difficulties in the attempts to determine its mass, charge, and velocity, and it was not until many years later that all these quantities were accurately found and the character of the positively charged particle fully known.

In 1896 the famous French physicist, Becquerel, discovered that the element uranium possessed the power of giving out a radiation which would affect a photographic plate. This interested Rutherford, and he used the rays of uranium to activate gases, measuring the velocity and decay of ionization for a number of gases ionized by them and by X-rays. The rate of decay of ions in a gas obeys certain laws that are worked out mathematically. Rutherford verified these laws experimentally. He also devised a very ingenious method of obtaining ions by the action of ultra-violet rays on a metal plate, and from his results showed that gaseous ions are produced at the surface of the plate instead of being due to the disintegration of metallic particles. The physicist, Zeleny, showed that under X-rays, the velocity of the negative ion was greater than the positive, while Rutherford showed the same thing in the case of ionization by uranium radiation.

All the methods employed gave practically the same results, and it was assumed that the ions produced in every case were identical. This all led to J. J. Thomson's famous paper of 1897 announcing the electron. Thus Crookes's strange cathode luminosity consisted of swift electrons. Electrons can be set free to-day by many means. They are produced every time the wireless is switched on, coming from the hot filaments of the valves, and in the cinema when the beam of the photo-electric cell is impinging

on the element selenium. They are also ejected from all radio-active substances.

The work which Rutherford had so far carried out on uranium had won for him the Coutts-Trotter Scholarship at Trinity College, and he had also been awarded his B.A. research degree. His fundamental research complete, Rutherford returned to the firing-line, as it were, and began to attack radio-active elements, at what has since been found to be the psychological moment. No man could have been more suited to the work ; he had devoted all his energies to an attempt to discover the nature of X-rays and had gained considerable experience and reputation in the technique of measurements.

It was found that the radiation from radium was not all of one type. When a small quantity of uranium salt was placed in a lead dish and then placed between the poles of a magnet it was found that three distinct sets of impressions were made on a photographic plate indicating that there were two kinds of radiation.

One was bent considerably towards one pole and the second slightly to the other. They must consist of some sort of charged particles since they were affected by the magnetic field. The particles which were bent considerably were negatively charged particles, while those that were bent slightly were positively charged particles. The former must be extremely small since they were bent so easily, and Rutherford identified them as the negatively charged particles discovered by Becquerel and as being similar to the electron. Rutherford called them beta-particles, and the rays beta-rays. The positively charged particles were of much greater mass since they were not deflected by any means so much as the beta-particles. These particles, which were to occupy the first decade of Rutherford's investigations and to be his greatest weapon, were called alpha-particles and the rays alpha-rays.

Rutherford began to study these rays. He was engaged in this work when there came an interruption of supreme importance. The brilliant research professor, Hugh L. Callendar, a Trinity man, retired from McGill University, Montreal, to take the chair at the Imperial College, London, and John Cox, Director of the MacDonald Physics Labora-

tory, visisted England and asked J. J. Thomson to nominate one of his students to fill the vacant chair of physics at McGill University.

Thomson was surrounded by a group of twenty-five brilliant students, from whom he could have selected anyone with complete assurance that he was not making a mistake, yet with praiseworthy unselfishness he chose Rutherford, his greatest jewel, for he knew that, in his own laboratory, Rutherford would accomplish wonders. There is no doubt that Rutherford was as loath to part from Thomson as Thomson was to let him go ; he was perfectly happy working for such a brilliant man, and maintained, as many others maintained, that there can only be one J. J., the man whose discovery of the electron has been ranked as having a greater influence on science than any discovery since the days of Galileo.

In this way John Cox was fortunate in securing Rutherford ; in fact, the whole world of science was fortunate that this move was made, for at McGill, Rutherford began the greatest part of his brilliant career.

He was not long enough at Cambridge to sit for a Fellowship, but he had been extremely fortunate in beginning his investigations under a man who trained him so well in the experimental study of radiation.

Rutherford even then possessed so intimate a knowledge of ions that he once remarked : " Ions are such jolly little beggars ; you can almost see them."

CHAPTER IV

CANADA AND THE FIRST GREAT DISCOVERY

THE McGill University is Canada's greatest. It comprises the McGill College and several others, and owes its origin to the philanthropy of James McGill, a native of Scotland, who early emigrated to Canada and made a fortune in the fur trade in the North-West. Settling in Montreal, he took a leading part in the city's affairs, and when he died in 1813 left £40,000 for the foundation of the College which bears his name.

Nearly eighty years later another great benefactor arose —Sir William MacDonald, who had a very great interest in the McGill University.

His benefactions to the McGill totalled some four million dollars, of which a small portion was set aside towards the erection of a physics building.

He endowed the chair of physics in 1891, and John Cox, a late fellow of Trinity College, Cambridge, became the first professor. He was given the task of supervising the designing of the buildings and for that purpose he toured the principal laboratories in the United States. In conjunction with the architects he designed a building that has the rare qualities of being beautiful in appearance and at the same time so well designed internally that even twenty years later no undue wastage of space was found.

The fabric cost £29,000. When it had been erected Cox asked Sir William for £5000 with which to equip it. He received £6000 !

Later, Sir William endowed a chair of research or experimental physics, and the first holder was Professor Hugh Callendar.

From 1892 to 1897 Sir William at different times spent £22,000 on further equipment and settled a sum of £30,000

to provide an income of £1500 per annum for the laboratories' salaries and upkeep and another £1000 to provide books for the library.

At the McGill University in the year 1898, at the comparatively early age of twenty-eight, Rutherford arrived to be head of the Physics Laboratory, and to continue his investigations into radio-active substances. Compared with the modern laboratory, that which awaited Rutherford was not too well equipped, but it was one of the finest of its time.

There was, of course, the usual period of 'sizing up.' Professors and students at McGill had heard much of Rutherford and his work and were wondering what kind of a man he was to get on with. They were soon to learn, soon to discover that he was one of the most delightful of men. He fell instantly into place, and in a few weeks was as intimate and friendly with his new colleagues as if he had worked with them all his life.

His ability as a lecturer increased with time, as he cultivated to an extraordinary degree that rare power of making the most difficult problems in physics appear simple. He would talk of electrons as if they were footballs and introduce a joke to illustrate a point.

The resources of his department were immediately utilized in prosecuting researches into all the then known branches of radio-activity. It was the beginning of a terrific onslaught, the like of which has rarely been known in the history of science. Within a period of eight years more than fifty papers were to be issued under his name, successfully bombarding one strategical point after another in the extensive campaign that was opening up the great territory whose existence Röntgen and Becquerel had discovered.

In 1899 Rutherford set the ball rolling with a paper describing the properties of uranium. He showed that besides the alpha- and beta-rays there were indications of the existence of some feeble rays of great penetrating power. They were in many respects analogous to Röntgen's X-rays.

Many other facts were given, and on reading the paper one is struck by the powerful manner in which one fundamental fact after another is blasted out of entrenched obscurity.

It is typical of the style Rutherford adopted for most of his future papers.

With McClung he published a paper containing many important fundamental data concerning the energy due to the Röntgen and Becquerel rays.

They ionized gases with the rays from uranium, thorium, and other radio-active elements and found that some of the radiations penetrated as much as 24·7 metres of air before being absorbed and that the absorption was immensely proportional to the pressure and density of the gas. From their results they deduced that the rays traversed 1/500,000,000 cm. before producing an ion in a gas, irrespective of the pressure. They then measured the heat radiated by the uranium. One gramme of the element radiates enough heat in 320 years to raise one cubic centimetre of water 1° C. On the other hand radium, 100,000 times more active, would raise one cubic centimetre of water 1° C. in a couple of hours.

Assuming that the energy absorbed in providing an ion is due to the work done in separating ions from the forces of their electrical attraction, they showed that the distance between the charges of the ions in the molecule is $1 \cdot 1 \times 10^{-9}$ cm., only 1/30 the diameter of the atom.

By means of an ingeniously devised platinum bolometer o their own, they measured the energy of Röntgen or X-rays, to give them their present-day name. They found that very little of the energy emitted on absorption was used in producing secondary rays, and that the heating effect was 1·95 gramme-calories per second for the rays they used. Sunlight normally has the heating effect of 0·035 gramme-calories per second. This shows the great power in radio-active substances.

R. B. Owens, of the engineering building at the McGill, found, while carrying out certain experiments on thorium, that puffs of air, draughts, or the opening of a door influenced the readings on his electroscope, sometimes cutting down their value to a third. The thorium radiation was behaving in a very inconsistent manner. A 'something' had been blown away from thorium by the draughts. This 'something' passed through paper, but not through metal foil or mica. The 'something' which appeared to emanate from thorium was christened 'emanation.'

Besides emitting an emanation, thorium had the property of infecting non-radio-active bodies and making them appear radio-active on their own accord. This activity was termed ' induced or excited ' radio-activity. Here were a heap of problems. ' Emanation ' was dealt with first.

Rutherford considered that it consisted of radio-active particles. He isolated some of the air surrounding thorium and found that, independent of thorium, it kept its activity for some months, but gradually lost its intensity. Extremes of temperature produced no variations.

Induced radio-activity was caused by it, which could be confined to a body charged with negative electricity. Thus only uncharged or negatively charged bodies could be excited, but the nature of the body or the type of conductor was immaterial.

Rutherford confined emanation to a negatively charged fine platinum wire and obtained an intense source of radio-activity. The body did not appear to have gained any appreciable increase in weight. It was found that after about twelve hours the activity had been reduced to half, and in another twelve hours reduced to one-quarter, and so on. The time taken for the activity of a given amount of a radio-active substance to decay by one-half is known as the half-period, and it was eventually established that the life of a radio-active was to be expressed in ' half-periods ' or ' half-lives.'

There were four possible explanations for this unusual phenomena :

1. The emanation was a kind of phosphorescence excited by radiation from thorium.
2. Deposition of positively charged gaseous ions produced in the surrounding gas by the radiations.
3. Deposition of particles of a radio-active molecule emitted by thorium.
4. Vapours of the radio-active substances.

So far as his knowledge at that time took him, Rutherford knew that the first was not tenable.

Meanwhile, Dorn announced that he had discovered an emanation from radium that had a half-period of four days. At first Rutherford, using an impure sample of

radium, was unable to confirm this owing to his finding little, if any, emanation being emitted and no discernible 'excited' activity. However, on heating this sample he obtained a comparatively enormous amount of emanation; 10,000 times the normal amount.

"Up to this point," said Rutherford, "I had been unable to obtain any definite evidence whether the so-called emanations were vapours of the radio-active substances. . . ."

Radium and thorium compounds when enclosed in a vacuum caused no appreciable lowering of it and no new spectral lines were observed on passing an electric discharge.

Then, early in 1901, P. Curie and A. Debierne found that radio-active substances in vacuum decreased the vacuum giving a radio-active gas. The containing tubes became phosphorescent and finally blackened while the substance was temporarily radio-active.

It appeared, therefore, that the fourth possibility was correct. Next Rutherford and H. L. Brook by measuring the rate of diffusion with other gases, came to the conclusion that emanation from radium was a radio-active gas of molecular weight between 40 and 100.

One distinct feature distinguished the emanations of radium and thorium. The second loses its radio-activity in a few minutes, while the excited radio-activity due to it lasts several days; in the case of the first the emanation lasts several weeks, while the excited radio-activity endures for a few hours.

Rutherford also came to the conclusion that radium emanation not only continued for long intervals to be a source of rays apparently similar in character to easily absorbed (or soft) Röntgen rays, but in some way manufactured for itself a positively charged substance which travels to the negative electrode and becomes a source of secondary radiation.

The discovery of emanation helped to explain why on heating thorium and radium compounds their activity increased up to a certain point owing to the expulsion of occluded emanation.

In comparison with radium emanations those of thorium had less ionizing power bulk for bulk, but they were more powerful than radium compounds at ordinary temperatures.

Rutherford concluded finally, in 1901, that thorium emanation was of the argon type of inert gas. That is an inert gas similar to helium.

In England, Sir William Crookes, by a laborious and ingenious chemical method, extracted a new substance, called uranium-X from uranium itself. The new material was highly radio-active, though small in quantity, while the original uranium compound after the separation was found to be far less radio-active than before.

The new uranium-X was found to decrease in power fairly rapidly, having a half-period of one month, but the original uranium compound increased in activity at the same rate.

Shortly before Crookes' announcement a young Oxford physical chemist decided to devote himself to research in radio-activity, and looking around for the best place to study, came to the conclusion that he could do no better than join the Rutherford clan at the McGill. This man was Frederick Soddy. He was twenty-three years old when he thus joined forces with a professor not yet out of his twenties.

The partnership lasted only two years, but it produced a cataclysmic effect in the realm of physics.

Working by a different method on the discovery of Sir William Crookes, Soddy found that the activity of uranium was not separable from the parent uranium; which contradicted Crookes, so Soddy asked two questions:

1. Is residual activity to be regarded as secondary radiation produced by the presence of uranium-X?
2. Is the residual activity caused by the action of a material substance capable of separation?

Experimental considerations answered the first question in the negative. It seemed to Soddy that if residual activity was caused by the action of a substance capable of chemical separation, that a constituent alpha-radiation could be separated from uranium, though all attempts hitherto had failed. There was one example—radio-active polonium—discovered by the Curies. It fulfilled in all respects the function of this hypothetical constituent since polonium was always closely associated with radium ores.

Rutherford and Soddy, with this view in mind, turned their attention to thorium compounds. They separated

from thorium a substance, thorium-X, whose activity slowly disappeared, while that of the parent thorium gradually reverted to normal. This producing and disappearing of activity was not affected by any known agents and proceeded independently of the physical and chemical conditions of the molecules. Rutherford and Soddy said that they believed that the source of this energy was to be found in a chemical change producing a new type of matter, while Soddy definitely proved that uranium gave only alpha-radiation and uranium-X beta-radiation.

These seemingly isolated facts and products, emanation, 'excited' radio-activity, uranium, and uranium-X and so on, were leading Rutherford and Soddy to a strange goal.

Meanwhile, another important discovery was made by Villard. Early in 1902, by a photographic method, he drew attention to some very penetrating non-deviable rays emitted by radio-active elements. This discovery was confirmed by Becquerel. Villard christened these rays 'gamma-rays.'

Thus the rays causing radio-activity were further complicated—alpha-rays, beta-rays, and now gamma-rays.

The gamma-rays were those Rutherford had noticed earlier. Radium and thorium emitted them in abundance and uranium but sparsely. They ionized gases a little, but possessed great penetrating power, going through as much as 3 inches of lead.

A lead wire, excited by thorium and radium emanation, also gave gamma-rays, possessing the same penetrating power as those from radium and thorium, but whose intensity diminished with time.

"This diminution with time," Rutherford said, "is probably directly connected with the ratio of decay of the other known types of radiation from excited bodies."

More reinforced concrete for the foundation of the theory of the cause of radio-activity.

Villard's experiments were repeated at McGill and provide material for a good story, and also an example of the thoroughness which Rutherford demanded in research work.

The Polish scientist, Godlewski, had joined the gathering. Attempts were being made to deflect the gamma-rays from radium by very powerful magnetic fields, but unsuccessfully.

However, Godlewski thought that the softer rays from actinium might be more amenable, and one day he found on his photographic plate indications that the gamma-rays from actinium had been deflected.

Dancing with joy, he greeted Rutherford, saying: "I have completely deflected the gamma-rays of actinium." "Do it again," replied Rutherford with a smile. "Certainly, I will," was the reply.

For week after week poor Godlewski tried to repeat his experiment, but without success. The apparent deflection was due to a flaw somewhere and was just one of Nature's unkind little jokes.

The non-deviability of the gamma-rays suggested that they were not cathode rays. X-rays ionized certain gases to a greater extent than they did air, while the cathode rays produced just a little ionization which was of the same intensity whatever the gas. The gamma-rays having the same small ionizing properties as the cathode rays, appeared, on the surface, to resemble them rather than X-rays.

Now an electron moving with the velocity of light has a mass approaching infinity and is unaffected by a magnetic field. Rutherford suggested that it was not improbable that gamma-rays were electrons emitted with the velocity of light.

Work on the emanations showed all the properties of a gas could be assigned to them, while their passage through cotton-wool or solutions did not rob them of their radio-active properties. The attraction that confined them to a negatively charged body suggested that the radio-activity was due to the transport of positively charged carriers of some kind which appeared to have the same velocity as the positive ion.

With his directness of mind he saw that in pursuing these investigations further he had a possibility of arriving at the secret of the source of radio-activity.

He found that emanation itself manufactured the positively charged particles, themselves a source of secondary radiation. Together Rutherford and Soddy ploughed their way through the uncharted sea of radio-activity and finally suggested that thorium compounds might be emitting a gas which constituted the emanation. They were getting nearer the solution of the problem.

What was the position in 1902?

Thorium produced thorium-X, emanation, and secondary or 'induced' or 'excited' radio-activity on bodies. All of which apparently came from thorium, an element, *not* a chemical compound of two or more elements. What, then, was happening? Was that hard, indivisible, minute sphere of Dalton's actually breaking up? It could not by all the atomic laws conceived by the nineteenth-century scientists do so. How could the fact that one element was 'growing' another be accounted for?

The answer soon came.

In November 1902 came the announcement 'some very interesting observations relative to the cause and nature of radio-activity have been recently made by Messrs. Rutherford and Soddy.'

From their experiments on thorium compounds they had arrived at the conclusion that the greater part of the radio-activity of thorium was due to non-thorium type of matter—thorium-X (Th-X) possessing distinct chemical properties.

It had a half-period of four days. The constant radio-activity of thorium, they said, was supposed to be maintained by the continuous production of Th-X independently of physical and chemical conditions. Th-X caused excited radio-activity and itself provided 20 per cent of the total thorium activity. Thorium freed from Th-X and excited activity possessed 25 per cent of the original activity. This latter Rutherford and Soddy believed to be due to a second non-thorium type of matter.

In experiments on the decay of thorium emanation they obtained an active deposit.

On these facts Rutherford and Soddy boldly set forth the theory of radio-active change. They stated that radio-activity was an atomic property independent of physical surroundings or chemical composition.

They said: "The normal or constant radio-activity possessed by thorium in an equilibrium value, where the rate of increase of radio-activity due to the production of fresh active material, is balanced by the ratio of decay of the radio-activity of that already formed."

Yes, the atom, after all, *was* disintegrating.

Changes were occurring inside the atom which meant

that radio-activity was simply a consequence of the bursting of the atom. The breaking up was spontaneous, and the atoms were disintegrated by choice independently of their age or physical conditions or their chemical constitution, but 'the rate of the change of the system at any time is always proportional to the amount standing unchanged.'

This led to the statement 'the proportional amount of radio-active matter that changes in unit time is a constant,' thus establishing for the first time the radio-active constant known as the half-period.

In its most violent form this new theory meant that the radio-active atom separated into two parts, one of which was a particle such as the alpha or beta and the remainder an atom of a new element requiring a new name. Experiment had shown this.

So, atoms of radio-active elements were constantly changing and withering away. Their disintegration was beyond the control of man.

The disintegration theory was simple—devastatingly simple.

Describing its effect many years later, Rutherford said: "The idea of the permanency of the atoms received a rude shock in 1902."

It was not a reformation—it was a revolution.

The theory was regarded by many as a flight of the imagination, and efforts were made to establish others more in line with the Daltonian atom. Rutherford, however, refused to turn against facts and stoutly championed his theory which is now accepted as a basic law.

Heraclitus was right when he said: "Change is everywhere; nothing is stable."

CHAPTER V

CONSOLIDATING HIS POSITION

THE Disintegration Theory permitted the prediction, qualitatively and quantitatively, of the whole complicated series of events, in connection with thorium especially and radio-activity as a whole.

To understand the effect that the paper written by Rutherford and Soddy had on the beliefs of the scientific world of the time, it is necessary to make a very brief survey of the history of the atom.

Democritus, a Greek philosopher of the fifth century B.C., regarded the universe as being made up of atoms of many sizes and shapes. By combination of these hard and indivisible particles everything in the world and nature, Democritus believed, was constructed. In the third century B.C. Epicurus argued that bodies are formed by collision and combination of an infinite number of atoms in infinite space. His theory was explained by Lucretius in his *De Rerum Natura*. In one of his writings, Sir Richard Gregory quotes a translation of part of *De Rerum Natura*:

> 'But solid seeds exist, which fill their place ;
> And make a difference betwixt full and space.
> These, as I proved before, no active flame,
> No subtle cold can pierce and break their frame.
>
> Tho' every compound yields ; no powerful blow,
> No subtle wedge divide or break in two.'

This conception of the atom remained forgotten through the ages and was not recalled until the beginning of the nineteenth century, when Dalton propounded his Atomic Theory, the rock on which modern chemistry is built.

Dalton had formulated his theory on the assumption that

the atoms were indivisible and the smallest form of an elementary substance; the subsequent laws of chemical change and combination were derived from that theory. Development in technique and the help of Avogadro's Hypothesis, formulated in 1811, led to the accurate determination of atomic weights. While, according to the Atomic Theory, all atoms of one element are identical in every respect, the weights of different elements are not the same. For example, taking hydrogen as unity, the weight of an atom of oxygen is 16, of carbon 12, of iron 56, of platinum 195, and so on.

Though these principles still hold good, a new aspect of the atom was provided by Rutherford's and Soddy's paper on disintegration. It destroyed at a blow the conception of the atom of Democritus and Epicurus and Dalton's theory of the indivisibility of the atom. The theory that the atom was a hard, solid mass—an unalterable particle of matter, was overthrown. Though the disintegration theory does not affect chemical combinations in the ordinary way, since in chemical reactions atoms are considered in bulk, it was the foundation of a new edifice of thought and investigation, an edifice on which many developments were to be built in the following thirty years, all of them beyond the early dreams of its originator.

During the centuries persistent and untiring efforts had been made by the alchemists to transmute metals. The alchemists had made many important discoveries of a kind and some of them were deep thinkers and philosophers of a high order, but through all their work ran a streak of cupidity. If it were granted that metals could be transmuted, then it were as well to transmute the base metal lead into the highly desirable metal, gold. That was their argument and the chief aim of their researches; but when Dalton postulated his Atomic Theory in 1808 the death-knell of the alchemists was sounded. Alchemy ceased to exist, and the whole of the nineteenth century was a period of intense scientific development, on what were then considered the only orthodox lines.

The creed of the alchemists was now vindicated. Charges of charlatanism were refuted, for here, on the showing of Rutherford and Soddy, was alchemy in an unexpected and

higher form. The young professor of physics and his assistant had shown that Nature herself was busy transmuting elements, that she herself was the great alchemist.

The beginning of the twenty century had opened up a new era in the world of science.

. . . . . .

Rutherford was building up around him a brilliant school of research. He was an ideal man for this purpose, for he was liberal-minded and gave away lines of research that a lesser man would have been much tempted to keep for himself.

The encouragement he gave his workers produced a great spirit in them; they became prolific and noted for the quality and quantity of their papers. But, and it is a big 'but,' every paper had to satisfy Rutherford first. No hasty conclusions, no inaccurate results, were allowed to emanate from the MacDonald Physics Laboratory.

Rutherford's fame was spreading far and wide, even before the publication of the disintegration theory, and the laboratory was attracting attention in all parts of the world. A list of some of the workers between 1898 and 1907, selected at random, makes impressive reading: A. S. Eve, Godlewski, H. L. Cooke, Boltwood, H. T. Brooks, Soddy, Barnes, Hahn, Max Levin of Göttingen, H. L. Bronson, R. K. McClung, R. W. Boyle.

The founder of the laboratory, Sir William MacDonald, did much to help the work on emanation by presenting the laboratory with a liquid air machine and three hundred dollars. With the latter gift Rutherford bought sixty milligrams of radium from Giesel, who refused to make any profit out of a co-worker in the world of science.

Using liquid air as the cooling agent, Rutherford condensed thorium and radium emanations, finding that thorium emanations volatilized at $-125°$ C. and radium at $-130°$ C.

Towards the end of 1902 Elster and Geitel showed that excited radio-activity could be produced from the atmosphere by exposing a negatively charged wire in the open air.

Rutherford said: "Since the earth is negative with regard to the upper atmosphere, the surface of the earth is

itself made radio-active . . . not only the surface of the earth, but also the whole interior surface of buildings is covered with an invisible deposit of radio-active matter. From the close similarity in the nature of this excited radio-activity from the air, with that from radio-active bodies, it is not improbable that the excited radiation from the air includes also some of the penetrating rays. If this is the case, our bodies must be continually subject in a small degree to something very like the Röntgen ray treatment which is now so popular in medical circles. It would also follow that the 'spontaneous' ionization of air observed in closed vessels . . . may be due . . . to the presence of these rays which so readily pass through the walls of containing vessels."

Rutherford decided that this required further investigation, and put H. L. Cooke on to the job. Rutherford also suggested that because there was radio-active matter in the ground, there must be penetrating rays coming upwards from the earth. The primary object, however, was to see if the ionization of the air observed in closed vessels was due, in fact, at least, to external radiation.

The rate of discharge of a gold-leaf electroscope in a brass vessel was observed.

At first Cooke could not get any indication that there were such rays, although he had been surrounding the vessel with the best known absorbent of penetrating rays, viz. lead.

However, Rutherford told Cooke to persist. "Try more lead," he said. It was done, masses of lead—five tons—eventually reduced the rate of discharge 30 per cent.

Cooke found that a layer of bricks increased the rate of discharge, and wood and metal which had been exposed to the weather and not cleaned, showed marked activity. Thus it was assured that the radiation, although coming in all directions, came chiefly from bricks, etc.

Indeed, the significance of the multi-direction radiation was not appreciated. In all probability the apparatus was being screened from *Cosmic Rays*, not discovered until some years later.

In 1895 Ramsay had found that helium was included in certain minerals which contained uranium and thorium

and in no others. This association was remarkable, as there appeared to be no obvious reason why so inert a gaseous element should be present in minerals which in many cases were impervious to water and gases.

Radio-activity threw a new light on this subject. The Transformation theory made one expect that the final or inactive products of transformations were to be found in radio-active minerals, and since these minerals were extremely old it was reasonable to suppose that the inactive products of the transformations would be found in some quantity with the radio-active matter as its invariable companion. The presence of helium in uranium and thorium minerals led Rutherford and Soddy to suggest that the helium might prove to be a disintegration product of radium.

A definite proof that helium was a disintegration product of radio-activity would be a convincing argument against those who still doubted its validity. Rutherford attacked this problem

Rutherford intuited that his alpha-particles were atoms of some substance, and here was the clue.

He subjected them to magnetic and electric fields, arguing that if the particles carried an electric charge, they should be deflected in passing through a strong electric or magnetic field.

In 1903 he showed that the alpha-rays were deflected by the fields as if they were positively charged bodies moving with great velocity.

From calculations from these experiments he determined that the velocity of the alpha-particles was 25 thousand million cm. per second, and the value of the electronic charge to the mass(e/m) as 6000 electro-magnetic units. These results were later confirmed by Des Coudres by a photographic method by which he obtained e/m for the alpha-particle as 6400 e.m.u. Later, Mackenzie found it to be 4600 e.m.u. and Hoff 4300 e.m.u.

These results showed that the alpha-particle was of an atomic mass comparable with the hydrogen atom. The e/m for hydrogen being 9643, indicated that if the alpha-particle carried the same charge as a hydrogen ion, its mass was twice that of hydrogen. Now if the charge on the alpha-

particle is twice that on the hydrogen atom then the mass of the alpha-particle is four times that of the hydrogen atom. The atomic weight of helium is 3·96, suggesting, therefore, that it is quite probable that the alpha-particle is a helium atom. But it could not be definitely proved what charge the alpha-particle carried. The e/m for the alpha-ray was varying considerably. The alpha-particle was being emitted over a wide range of velocities, so that only an approximate value was being obtained of its average velocity.

Rutherford and Soddy found that both radium bromide and radium emanation gave helium. On the disintegration theory they calculated the amount of helium and emanation emitted by radium.

It was assumed that the alpha-particle was positively charged and had a mass twice that of the hydrogen atom, but in this case only a small number escaped into the air, the majority were occluded. They estimated that the number required to give a 100-gm. calories of heat per hour was 2400 million per second. From this they deduced that a gram of radium emitted, allowing a wide margin, 0.021 to 0.21 cc. of helium per year.

Said Rutherford : " The determination of the mass of the alpha-body, taken in conjunction with the experiments on the production of helium by emanation, supports the view that the alpha-particle is in reality helium." The experiments of other researchers supported this view.

After two years with Rutherford, Soddy returned to England to join Ramsay in his helium-alpha-particle researches.

Next Rutherford announced : " There is evidence of at least five distinct changes occurring in radium, each of which is accompanied by the expulsion of an alpha-particle. One of the products of these changes is the radium emanation. It is of interest to calculate the volume of emanation occluded in radium in a state of radio-active equilibrium."

The volume was found to be between 6- and 60-hundred thousandths of a cc. per gram per day.

This was the first attempt to co-ordinate the radio-active series.

Rutherford also found that radium emanation was

responsible for three-fourths of the activity of radium and was unaffected by heat.

At the British Association Meeting in September 1903 Rutherford said that the radio-active processes repeat until no more alpha-particles are emitted, that the disintegration theory fits all known facts, but it involved the existence in the atom of a store of energy hitherto unsuspected.

Simply expressed, 1 lb. of radium emits energy equivalent to 10–100–one thousand H.P. 'on the disintegration hypothesis; this energy is derived from the latent energy in the radium atoms and is released in successive stages from their disintegrations.'

Rutherford suggested that it existed as kinetic energy of motion of the atoms in closed paths with velocities comparable with that of light, and disintegration was the moving off at a tangent of one or more of these particles of an atom.

Commenting on his suggestion, Rutherford made a statement that to-day appears remarkably prophetic: "If this be the case," he said, "it seems probable that the atomic energy of elements not yet found to be radio-active is of the same order of magnitude and may be set free by methods of which we are not yet cognisant."

Crookes now found that thorium separated from thorium-X gradually recovered its original activity, while the thorium-X lost activity.

So another fundamental statement was made by Rutherford: "At any time the sum total of the two activities is a constant." This is known as the 'activity sum constant.'

Thus it being proved that Th-X was being continuously produced by thorium, Rutherford added: "The production of thorium-X by thorium and of emanation by Th-X and of the matter causing excited activity by the emanation, are all charges of the same type, although the rates of charge are distinct." Similarly for the uranium series. In the case of radium 'the first product, emanation, is almost completely occluded, and the later products, being solid, are retained; thus the activity of a radium salt after it has been obtained from solution by precipitation rises to several times its original value.'

With all the three elements it had been found that a part

of the radio-activity was non-separable, emitting only alpha-rays and beta-rays in the last stages. "In all cases," said Rutherford, "the radiation from any type of active matter is a measure of the amount of the next type produced."

The radio-activity, therefore, of thorium-X, given time, is a measure of emanation, assuming in all cases that the alpha-particle projected is an integral portion of the atom of the radio-active element.

On this view the spontaneous heat emission of radium salts discovered by Curie (the air surrounding a radium compound is always a few degrees above the surrounding temperature) is explained by the internal bombardment by the alpha-particles shot off and entangled in the molecules of the substance.

Some idea of the tremendous heat given out by radium emanation was given by Rutherford in a lecture many years later. He said: "Suppose in imagination we could obtain a substantial quantity, say a kilogram, of radium emanation and introduce it into a heat-resisting bomb. At the end of two hours the heat would be liberated at a rate corresponding to 20,000 kilowatts, and the bomb would be melted unless it were cooled very efficiently." However, it would require 200 tons of radium to provide one kilogram of emanation emitting gamma-rays equivalent to 1000 kilowatts.

The heat measurements of Rutherford and Barnes, in combination with Lord Rayleigh's determination of the amount of radium in the primary sedimentary rocks, have settled the long-drawn-out controversy between Kelvin and Huxley as to the age of the earth. Indeed, there is an embarrassment of riches, for there is more than sufficient radium in the earth to prevent its cooling, so that, as Rutherford said: "The geologist can fill in the blank cheque as he will, and can postulate successive heatings and coolings such as the series of ice-ages and mountain-building and volcanic activity seem to require."

Later, it was shown that the amount of lead or helium accumulated in radio-active ore bodies of various ages provided a useful measurement of geological time. Thus it is possible to say of a piece of pitchblende, with some precision, that it has existed in its present form for a period

of 700 million years, and, further, it is possible to give the higher figure of 2000 million as the age of the earth.

Late in 1903 the question was raised, 'Does radio-activity of radium depend on its concentration?' Many scientists said it did, others were doubtful, and some said "No!"

Rutherford, however, said nothing until he had solved the question experimentally, and came to the conclusion 'that a distribution of the radio-active matter over a 1000 times its original volume has no appreciable influence on radio-activity,' and he found at the same time that 'the radio-activity of radium is not influenced by its own intense radiation.'

The experiment brought out another obscure point. 'It is thus improbable that the energy given by radium is due to an absorption of an unknown external radiation which is similar in character to the radiation which is emitted.' The answer was 'No.'

Gamma-rays were becoming much in evidence. A. S. Eve showed that the more penetrating X-rays after passing through thick metal screens were similar in action to the gamma-rays of radium. The experiments showed that the relative conductivity imparted to gases by X-rays is a function of the penetrating power of the rays employed.

"Eve's results," commented Rutherford, "remove the strongest objections that have been urged against the common belief that the gamma-rays are an extremely penetrating type of Röntgen rays." It was assumed that the rays originated in the radio-active atom at the moment of expulsion of a beta-particle. Since these rays were independent of radio-active concentration it was assumed that they arose from the disintegrated atom and were not secondary rays produced by beta-ray bombardment within the molecule.

Rutherford also pointed out that on the theories of Stokes and J. J. Thomson a secondary group of gamma-rays should be emitted by the beta-particle bombardment owing to the great speed of the particle.

In 1904 Rutherford was asked to deliver the Royal Society Bakerian Lecture for that year. He had been elected a member the previous year and in 1902 had been awarded the Copley Medal. This lecture was a memorable one and

earned for Rutherford the Rumford Medal. The title was 'The Succession of Changes in Radio-Active Bodies.'

He explained the Disintegration Theory; how each product has its own rate of decay and how its activity was the measure of the rate of change of the next product.

But there were two products 'excited' radio-activity of the emanation-X of thorium and radium which did not decay at the predicted rate.

Boldly Rutherford postulated that this was due to the formation of a rayless product between emanation-X and its active product. In other words, no alpha-, beta-, or gamma-rays were emitted, but the intermediate product was formed by an internal rearrangement of the emanation-X atom and was detectable only by its effect on the change that followed.

The bold prediction of the existence of a material substance of which no single physical property was known, beyond the fact that it caused a disarrangement, struck Rutherford's colleagues as a most remarkable thing, and thirty years later, when the circumstances were recalled to Rutherford, he himself confessed that he was impressed by his own boldness.

Scientists may well believe in an undetectable ether because of its known physical properties, but in this case a scientist believed in a substance without any physical properties other than that of a go-between.

With Barnes, Rutherford measured the half-periods of the three rapid changes for radium, 1st only an alpha-particle emitted, half-period 3 minutes, 2nd rayless, half-period 20 minutes, and 3rd alpha-, beta-, and gamma-rays, half-period 28 minutes. Rutherford came to the conclusion that beta- and gamma-rays appear only in the last rapid change of each of the radio-elements.

Other changes were accompanied by the emission of alpha-particles only.

The last rapid change in the uranium, radium, and thorium series, Rutherford thought, was far more rapid and explosive than the preceding since it emitted alpha, beta, and gamma altogether.

The three rapid changes were followed by a slow series.

Slow products were found, in the case of radium, to emit

alpha-rays and an unusually large proportion of beta-rays which diminished in activity in 3 minutes, while the alpha-ray activity remained unaltered.

It is evident that at the commencement of 1904 Rutherford was well on the way in the search for an orderly system in radio-active disintegration.

He had not, however, obtained definite evidence that the alpha-particle carried a positive charge when inside the atom; therefore it must gain it in some way after its expulsion. Here, perhaps, is the first indication of considerations that were later partly responsible for the conception of 'potential barriers' within the atom.

Radium, Rutherford had surmised, was not a parent radio-element but was 'grown' by uranium or thorium.

Rutherford said: "I have taken solutions of thorium nitrate and 'emanating substance' of Giesel freed from radium and placed them in closed vessels. The amount of radium was determined by drawing off emanations at regular intervals into an electroscope. A sufficient interval of time has not yet elapsed to settle with certainty whether radium is being produced or not, but the indications so far obtained are of promising character."

In June 1904 the first edition of the book that immediately became a standard work on radio-activity was published, Rutherford's *Radio-activity*.

In a review in *Nature*, H. A. Wilson wrote: 'Amongst those who have contributed most to the exact study of radio-activity, Professor Rutherford occupies the foremost place, so that a connected account of the experimental results obtained and theories proposed to explain them from his pen, cannot but be welcomed by all those interested in the subject.'

Work was now extremely rapid on the working out of the series. The new radium elements were now so numerous that instead of giving cumbersome names they were called radium-A, 'radium-B,' and so on in derivative sequence.

Commencing with radium he obtained the following sequence: Ra→emanation (Radon)→radium-A→radium-B → radium-C → radium-D → radium-D^1 → radium-E and finally radium-F.

Said Rutherford many years later " but attention should

be drawn to the extraordinary simplicity of the relations which connect together the whole series of transformations."

In 1904 Rutherford had said: "Since radium-A breaks up with an expulsion of an alpha-particle, some of the residual atoms constituting radium-B may acquire sufficient velocity to escape into the gas, and be thus transferred by diffusion to the walls of the vessel."

This was a statement of the second principle later used by Hahn and others to discover new radio-active elements. Another fundamental fact that might easily have been neglected but for Rutherford's eagle eye.

It was some years before further important developments were made in regard to the radio-active series. Meanwhile there remained the problems of the alpha- and gamma-rays.

Rutherford and Barnes investigated the heating effect of the gamma-rays and found that, in contradiction to other investigators, beyond all doubt they supplied little if any of the heat from radium.

'In our experiments,' wrote Rutherford, 'we conclude from this that the gamma-rays do not supply more than a small percentage of the total heating effect of radium.'

Such experiments occupied a considerable amount of time at the McGill, but they were very necessary.

The beta-rays presented no difficulties in the determination of their sign-negative,—but the alpha-particle provided a quandary. It was known that a positive charge was left behind in a vessel containing radium; that the particle was deflected by a magnetic field as if it were positively charged. "It is to be expected," said Rutherford, "that this charge should be easily detected; but all the initial experiments made for this purpose resulted in failure."

From the fact that only four radium products gave alpha-particles and one beta, it was theoretically expected that four alpha-particles were expelled to one beta. Rutherford made several attempts to solve this problem and after some failures modified his plan of attack and eventually achieved success.

The alpha-particle was proved to have a positive charge. In his own words 'the settlement of this problem has been for the last few years the most important problem in radio-activity. The proof that the alpha-particle is a helium

atom carries numerous consequences of first importance in its train.'

From his data Rutherford deduced that one gramme of radium bromide emitted 35 thousand million particles per second.

In equilibrium the activity was four times this. Thus one gramme of radium bromide in equilibrium gives 140 thousand million particles.

'The number of alpha-particles,' wrote Rutherford, 'expelled per second from one gramme of radium is a most important constant, for on it depends all calculations to determine the volume of helium, the heat of emission of radium, and also the probable life of radium and other radio-elements.'

At this period a very timely event occurred in another part of the world, namely, the invention of the spinthariscope by Sir William Crookes. It was based on the discovery by him and also by Elster and Geitel of a property of the alpha-ray which was subsequently to prove of great importance to radio-active measurements.

If a screen of phosphorescent zinc sulphide is exposed to the alpha-rays, a brilliant luminosity is observable where the particles hit the screen, and it was discovered that this luminosity consisted of minute scintillating points of light of short duration.

The spinthariscope was an inexpensive and simple little instrument which showed the upheaval in the radio-active world. It consisted of a small metal tube, one end of which contained a lens; at the other was the zinc sulphide screen. Just in front of the screen, inside the tube, was a minute speck of radium on the head of a pin. When taken into the dark and the eye was placed at the lens, which could be focused, sudden flashes of light could be seen on the screen. Every scintillation on the screen of the spinthariscope meant the emission of an alpha-particle.

Rutherford easily counted the number of scintillations—about two a second—and as he knew the weight of the radium salt on the pin-head, he was able to calculate the speed of disintegration of radium.

It was a new chapter of Physics and Chemistry. That of matter in evolution. The zinc sulphide screen shared, with

the Wilson Cloud Chamber, the position of being the most important of all instruments in radio-active research.

In a gramme of radium thirty-five billion atoms of radium were disintegrating every second. This meant that radium was losing its activity at the rate of one per cent every twenty-five years. Rutherford calculated that at the end of 1700 years radium would have lost half its strength—a slow but definite process.

From Rutherford's data the rate of disintegration of other elements which ejected alpha-particles was calculated. Uranium, for example, takes six billion years for half of it to disintegrate.

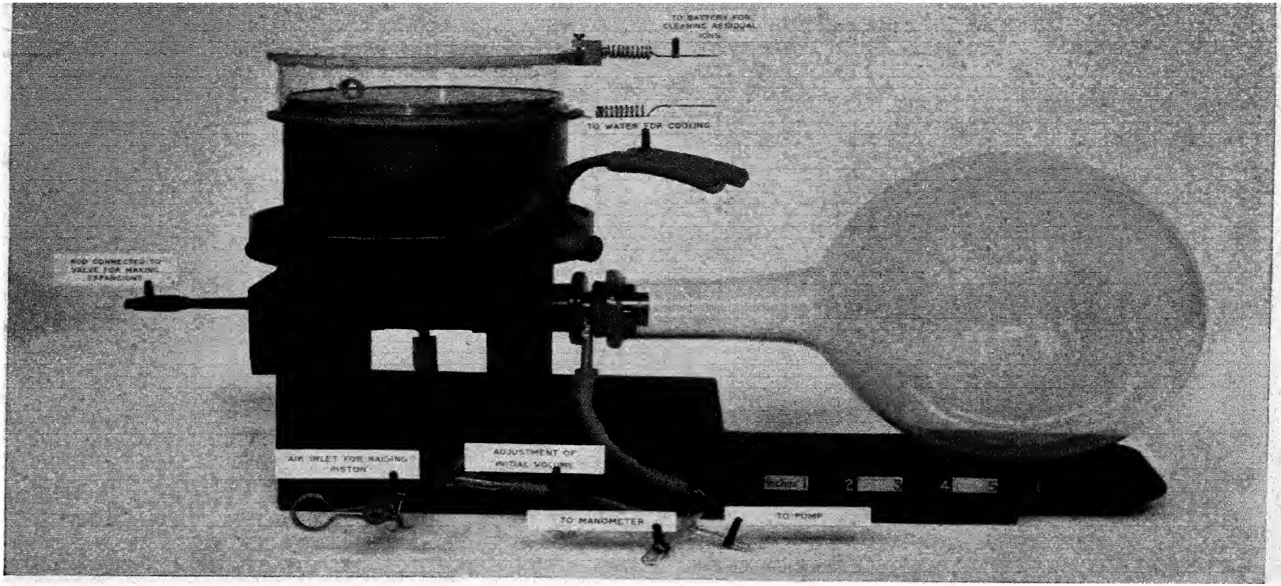
W. H. Bragg suggested that the peculiarities observed by the absorption of alpha-rays could be explained by supposing that the massive alpha-particle with its high velocity travelled in nearly a straight line through the gas and expanded its energy in ionization until it fell below a certain velocity. This necessitated the assumption of a certain critical velocity below which the particle is unable to produce the characteristic effects. Thus, the alpha-particle should have a definite range of travel in the gas depending on its initial velocity. Mme Curie had found that if a film of polonium was placed below a hole in a plate, the gas above that hole was not ionized when the film was more than 4 centimetres below it.

Experiments were at once begun to test this suggestion by examining the path of a pencil of rays from radium. It was found that the alpha-particles had characteristic ranges, depending on their initial source. This led to experiments on the ranges of the alpha-rays in different gases and metals and a study of the laws of absorption of the alpha-particle.

It was found on measuring the velocity of alpha-particles from radium-C that after 7·0 cm. no photographic action was caused. The velocity at this period was 4/10 of the original velocity. Thus the characteristic range of an alpha-particle determined the radio-element of its origin.

In 1906 Rutherford used Sir James Dewar's discovery that coco-nut charcoal absorbed gases, producing a vacuum, in conjunction with radium emanation. He said:

"In a recent investigation I had occasion to pass the



THE 'INSTRUMENT WHICH . . . IS THE MOST ORIGINAL AND WONDERFUL IN SCIENTIFIC HISTORY'

The Original Expansion Chamber used by C. T. R. Wilson in 1912.
From the exhibit in the Science Museum, South Kensington, London.
Reproduced by permission of the Cavendish Laboratory, Cambridge.

The damp, dust-free air chamber is above the black cylindrical piston. It is forced down suddenly by pushing the labelled rod which opens the valve of the glass vacuum chamber on the right.

radium emanation through a tube filled with coco-nut charcoal and was surprised to find that the emanation was completely absorbed by it."

It was found that air containing emanations of thorium, radium, or actinium were absorbed at ordinary temperatures without cooling, though slowly because of their slow rates of diffusion.

Powdered willerrite mixed with the charcoal shows the gradual absorption by increasing phosphorescence. It did not matter whether the charcoal was full of air or not, a gas containing emanation was rapidly absorbed with the same effect as if the gas had been placed in a sealed vessel.

On heating to red heat the surge of air from the charcoal swept out the emanation.

It enabled small amounts of emanation to be transported. It also solved the problem of keeping radium in sealed vessels since it absorbed all gases emitted and also prevents emanation contaminating the surroundings.

* * *

At the end of 1906 Rutherford and Boltwood definitely concluded that lead was the end of the radio-active series of uranium.

$$\underset{(237{\cdot}5)}{\text{Uranium}} \xrightarrow{(-3\alpha\text{-particles})} \text{Ra } 225 \xrightarrow{(-5\alpha\text{-particles})} 205 \text{ (lead } 206{\cdot}5)$$

In January 1906 appeared a completely revised edition of *Radio-activity*. R. J. Strutt (Lord Rayleigh) in reviewing it said : " Prof. Rutherford's book has no rival as an authoritative exposition of what is known of the properties of radio-active bodies. A very large share of that knowledge is due to the author himself. His amazing activity in this field has excited universal admiration. Scarcely a month has passed for several years without some important contribution from the pupils he has inspired, on this branch of science ; and what is more wonderful still, there has been in all this vast mass of work scarcely a single conclusion which has since been shown to be ill-founded. . . ."

Could a brother-scientist have given better praise ?

Another phenomenon which Rutherford found was that

when alpha-particles passed through matter, some of them were deviated from their original direction and underwent the process known as scattering.

Rutherford showed this by a photographic method, in which the image of a narrow slit produced by a beam of alpha-particles had sharply defined edges when the experiment was performed in an evacuated vessel. If air was admitted to the apparatus, or if the slit was covered with a thin sheet of matter, the photographic trace of the pencil of alpha-rays faded off gradually on each side of the centre. At the time this discovery seemed insignificant, but it was actually the key to the door that, five or six years later, was to open and reveal the structure of the atom.

Otto Hahn was a notable arrival at the McGill in 1905.

He had been researching with Ramsay, who had provided him with some thorianite for the purpose of extracting radium from it. After the process had been in operation for some time, Ramsay and Hahn discovered to their surprise that the residue which had been concentrated was becoming increasingly radio-active, though there was little radium produced. This phenomenon in the concentrated residue led to the discovery of a substance many thousand times more radio-active than thorium. Hahn came to McGill to find out what the new element was.

Hahn was excitable and enthusiastic, while his command of English was not complete. At first Rutherford was puzzled and rather sceptical, but Hahn showed him the presence of the emanation from thorium, which had a half-life of 53 seconds, and Rutherford became enthusiastic over this discovery of radio-thorium, an important and powerful member of the thorium family.

Hahn was an organic chemist, and it was this visit that was primarily responsible for his changing over to inorganic chemistry. Incidentally, through Hahn we have an idea of the disadvantages under which the McGill scientists worked at that time.

"We determined," said Hahn, "the magnetic and electrostatic deflections of the alpha-rays from radio-thorium. The apparatus was fitted up in a dark cellar. The Toepler (vacuum) pump functioned slowly and not always satisfactorily, and many photographs had to be taken, for there

was a very real danger of radio-active contamination. Rutherford was not to be discouraged by initial failure, however, and he was able to establish conclusively that the alpha-rays from radio-thorium and from its transformation products are also helium particles."

Hahn stayed with Rutherford for a year or so, during which time he discovered radio-actinium and carried out further investigations on the thorium family, work which he afterwards continued brilliantly in Berlin, bringing him great fame.

On 4 January 1907 the workers at the McGill were prey to a mixture of elation and depression. It had been announced that Rutherford had been appointed Langworthy Professor of Physics at Manchester University. He well merited the 'promotion' and they were glad, but they did not want to lose him.

Rutherford's work in Canada can be summed up in the words 'radio-activity and the alpha-particle.'

In just over eight years he had accomplished more than most scientists do in eighty. It was the most vital chapter of his life. The crowning glory of this period was that revolutionary and one-time heretical theory whose announcement he shared with Soddy—the disintegration theory.

The disintegration theory had raised a lot of opposition, particularly from that G.O.M. of science, Lord Kelvin. At one meeting he said : "I venture to suggest that etherial masses may supply energy to the radium," and his view of radio-activity at that time, "A simple prima facie view is to regard the gamma-rays as merely vapours of radium," the beta-rays he had accepted as electrons, the "alpha-rays are atoms of molecules of matter, probably atoms of radium, or perhaps molecules of bromide of radium, either deprived of electrons or having less than their neutralizing quantum." Eventually he was convinced that Rutherford was right, giving rise to the following anecdote.

In 1904, when Lord Kelvin did not agree with Rutherford's point of view, Lord Rayleigh was wholeheartedly in agreement with Rutherford, and, as he said : "With some lack of proper respect and deference, I asked Lord Kelvin if he would make a bet with me that within three or maybe six months, he would admit that Rutherford was right.

Within the allotted period Lord Kelvin's views had come round, and at a meeting of the British Association he made a public pronouncement in favour of the internal origin of the energy of radium. Next time I saw him he came up to me and at once said : 'I think I owe you five shillings. Here it is.'"

One of the secrets of Rutherford's success at McGill was that he was a born experimentalist and possessed exceptional tenacity of purpose ; he refused to be moved one iota from a predetermined course by the smallest extraneous interest, pushing forward in his investigations with judgment, ingenuity, and courage. His researches there stand amongst the greatest that the world of science has ever seen ; they are meritorious both for themselves and for their revolutionary effect on scientific thought.

He advanced directly along the royal road of physics, seldom if ever wandering into blind alleys ; in fact, his progress was so rapid that he was deterred from adventuring into mathematical physics. Yet whenever occasion demanded he never lacked the necessary mathematical equipment essential to the interpretation and calculation of his work.

Combined with his qualities as a scientist was his ability to encourage others and maintain their loyalty. Rutherford never allowed the importance of his work to deprive him of an atom of humanity ; nor, when it was clear that he was making a name for himself that should stand beside the highest in the history of science, did he adopt an unnatural dignity or aloofness. He was always helpful and extended a never-failing friendship towards his colleagues and assistants, especially those of foreign nationality. He was sincere and unassuming in his dealings with his students, and the Germans in particular were constantly surprised and admiring. They had imagined that such a distinguished professor would be an unapproachable person, conscious of his dignity.

All gatherings at McGill bore the mark of Rutherford's outstanding personality. There was a combined physics and chemical colloquy, and it not infrequently happened that the beloved alpha-particles found their way into the discussions which followed a lecture on one problem or

another in organic chemistry. Quite unintentionally, but nevertheless to the enjoyment of all, the most topical problems of radio-activity would suddenly become the central theme of conversation.

Hahn admired Rutherford both as the scientist and the man, and was most impressed with his modesty and unassuming manner. He was delighted when he once found the professor sweeping the snow away from the front of his house with all the enjoyment of a boy, more still to be a guest of Rutherford's at his home, where many pleasant evenings were spent listening to Mrs. Rutherford at the piano or the spirited yarns of Rutherford himself.

One day in 1906 a photographer went to McGill to take a photograph of Rutherford at work in the laboratory. At first Rutherford was reluctant, but at last consented to pose at his alpha-ray apparatus while a few flashlights were taken. The photographer, however, did not consider that the great professor was dressed elegantly enough. He was shocked that no white cuffs peeped from the ends of the professor's jacket sleeves.

But a way out was found. Hahn came forward and volunteered the loan of his loose cuffs, and the photographer arranged them so that they protruded well beyond the sleeves, being then quite satisfied with his model. The result of that morning's work was a picture of Rutherford seated alongside the apparatus with which he carried out his epoch-making experiments on the alpha-rays and also a first-class ' portrait ' of the white cuffs of a young student who regards his association with the greatest master of physical research as one of the treasured periods of his life.

It can be said that Rutherford became the father of two children born within twelve months of each other ; his daughter, Eileen, and what may be termed the NEW ALCHEMY.

Between them, Rutherford and Soddy had wrested from Nature one of the most important of the secrets she has been compelled to give up since research had earned the name of a science, and they had brought investigation into a new domain of transient chemical elements. In this domain investigators have found the main problems in physical chemistry ever since,

The thirty-years-old professor was '. . . a man resembling the alpha-particle in his local concentration of energy . . . inimical to leisure,' and he could 'arouse enthusiasm in anything short of a cow or a Cabinet minister. Frank and genial he could discuss any subject and smoke almost any tobacco.'

CHAPTER VI

FIRST YEARS AT MANCHESTER

WHEN Rutherford left McGill and transferred his researches to Manchester, he left behind him a tradition which, besides making the McGill University famous for all time throughout the scientific world, acted as a source of inspiration to those whom he left behind and those who have since entered the laboratory of the McGill University.

His successor at McGill was A. S. Eve, now Emeritus Professor of Physics of that University, who has since carried out many notable researches, furthering our knowledge of radio-activity.

At Manchester, Rutherford discovered a comparatively new laboratory founded in 1900. Sir Arthur Schuster had given much thought and care to its design and equipment, and it included a liquid air machine. Thus Rutherford, with the least possible delay, was able to continue his work. He found himself in an ideal post, little teaching, little administrative difficulties, and much research facility. For his experimental work he found that he had in William Kay a young, energetic, and an exceptionally capable and loyal laboratory steward. This was the man behind much of the practical work of the laboratory. A laboratory steward's name never appears before the world of science, but hard work on his part coupled with ingenuity of mind and cleverness of fingers has done inestimable service in the evolution of modern research apparatus.

Rutherford's researches were now mainly confined to the alpha-particle. He sensed that in the proper study and investigation of its nature lay the key to the many secrets

of radio-active disintegration, and that thereby he would obtain considerable insight into the mysteries of the atom.

The electron had now been very thoroughly investigated, but the evidence so far gained showed that the atom was not composed entirely of electrons. There was something else remaining in it. The electrons could not themselves account for the mass of the atom or the latter's normal neutral charge. What was that 'something'?

In 1886 Goldstein had studied the rays in a Crooke's tube, and by making a hole in the cathode had found that as the cathode rays flowed away from the cathode a stream of particles flowed towards it. Because of the grid-form of the cathode, these rays appeared as canals and were called the canal-rays (kanal strahlen). Goldstein found that the canal-rays were positively charged particles, whose mass was some thousands of times greater than that of the electron.

An instrument which has played an important part in the identification of these particles—and eventually of the transmutation of the elements—is the mass spectograph invented by Aston. Aston developed it further after the war.

With its aid calculations concerning the mass, and charge and velocity of alpha-particles can be made, and it has played an important part in the history of the atom. J. J. Thomson discovered the following facts:

1. That positive electricity was invariably associated with particles of atomic nature:
2. That no positive charge could be found in any particle with a mass less than that of the hydrogen atom:
3. That if the charge in the hydrogen atom is taken as unity, all the remaining atoms investigated held two or more positive charges.

Thus, the electron is the unit of negative electricity, and the hydrogen atom the unit of positive electricity. The mass of the hydrogen atom is 1846, that of the electron, and since the atom is positively charged, it must have lost an electron, and therefore the neutral hydrogen atom is composed of one electron and a positive particle.

Rutherford first investigated the possibility of uranium being the parent of radium. Boltwood had shown that there was an appreciable amount of radium formed in uranium solution; and since radium itself decays in about 2000 years, it must have a parent to keep up the supply.

In 1907 Boltwood said that he had obtained actinium from uranium, and that it became radium-C at a constant but rapid rate. Rutherford investigated this.

He found that actinium itself did not produce radium, but in the ordinary actinium preparations there was another substance which was being slowly transformed into radium. Thus the parent of radium was quite distinct from actinium. Rutherford suggested that it was probably the long-looked for intermediate transformation product between uranium and radium.

In view of Rutherford's statements, Boltwood continued observations, and eventually he separated a new element—'Ionium.'

In a letter to *Nature* Rutherford said: 'Dr. Boltwood is to be congratulated for his admirable work on this very difficult problem. . . ."

Since it appeared that uranium and thorium were two independent elements, Rutherford suggested that uranium might be genetic to actinium; but experiment ultimately showed that this idea was not very probable, whereupon Rutherford offered the suggestion that actinium was a branch decendant from some member of the uranium family, his idea being that there was a possibility that at one stage of the disintegration two distinct substances were produced, the alpha-particle being expelled and two distinct rearrangements of the atom taking place.

It was noted that actinium resembled thorium. Now, if ionium is completely separated from uranium and radium, it will grow radium at a constant rate, and the growth of radium observed is a measure of the breaking-up rate of ionium.

Boltwood found that one three-thousandth broke up, giving a period of about two thousand years. Below is given the genealogical table for some twenty-six radio-active substances known in 1907.

URANIUM-RADIUM SERIES

	Element	Half-period	Radiation emitted Alpha	Beta	Gamma
	Uranium	5×10^9 years	X	—	—
Giving	Uranium-X	22 days	—	X	X
,,	Ionium	?	X	—	—
,,	Radium	2000 years	X	—	—
,,	Radium Emanation	375 days	X	—	—
,,	Radium-A	3 minutes	X	—	—
,,	Radium-B	2·6 minutes	—	X	X
,,	Radium-C	19 minutes	X	X	X
,,	Radium-D (Radio-lead)	40 years		Rayless	
,,	Radium-E	6 days		Rayless	
,,	Radium-F	15 days	—	X	X
,,	Radium G	?	X	—	—
,,	....				

THORIUM SERIES

	Element	Half-period	Alpha	Beta	Gamma
	Thorium	10^{10} years	X	—	—
Giving	Meso-Thorium	?	—	X	X
,,	Radio-Thorium	800 days	X	—	—
,,	Thorium-X	37 days	X	—	—
,,	Thorium Emanation	54 seconds	X	—	—
,,	Thorium-A	11 hours		Rayless	
,,	Thorium-B	1 hour	X	—	—
,,	Thorium-C	?	X	X	X
,,	....	?			

ACTINIUM SERIES

	Element	Half-period	Alpha	Beta	Gamma
	Actinium	?		Rayless	
Giving	Radio-Actinium	195 days	X	—	—
,,	Actinium-X	10 days	X	—	—
,,	Actinium Emanation	37 seconds	X	—	—
,,	Actinium-A	34 minutes		Rayless	
,,	Actinium-B	3 minutes	X	X	X
,,	....	?			

It will be seen that seventeen give alpha-rays and beta-rays, four give beta-rays, and five no rays at all.

The transformations in the case of the ejection of the alpha-particle can be easily understood, but this is not the case with regard to the comparatively weightless beta-particle or rayless changes.

Rutherford supposed that the mass of the atom was not appreciably altered by the last two transformations, which took the course of an internal rearrangement of the part of the atom, or, possibly, that the atom expelled a particle at too low a velocity to be determined by electrical methods.

At a lecture at the Royal Institution in 1907 Rutherford accepted the view that the gamma-rays are equivalent to the X-rays. The latter are supposed to be electro-magnetic impulses in the ether, set up by impact or escape of electrons from matter, and they are akin in many respects to the very short wave of ultra-violet light. Various theses were offered to explain whether the beta-rays were of the corpuscular or wave-form.

But the alpha-particles are, for the moment, the most important. Their power is considerable in comparison with that of the beta- and gamma-rays. They are atomic bodies with a velocity of 6000 miles per second, and it is their great energy of motion that gives the heating power to radium, while they are responsible for most of the ionization in the neighbourhood of radium.

The alpha-particle plunges through every molecule in its path, producing positive and negative ionization, and ionizes some 100,000 molecules on an average before its life is over. Being heavy and moving with high velocity, it carries almost all before it and, unlike the beta-particle, is not easily deflected.

Their effective range now was of great help in deciding how many radio-active elements giving alpha-particles were present in a mineral. For example, ranges of 7 cm., 4·8 cm., 4·3 cm., and 3·5 cm., indicate that radium-A, emanation, and radium itself are present.

The next step was to identify the alpha-particle with the helium atom. Rutherford's observations on the ratio of the charge to mass of the alpha-particle had led to the supposition that there was a relationship, but there was no definite proof. It was "*the most pressing of the unsolved problems.*"

The riddle was one of unparalleled difficulty unless some new method of attack could be devised, for it was necessary to detect the emission of a *single* alpha-particle.

Eventually Rutherford in co-operation with Geiger

devised a method, which was based on a discovery by his friend Townshend.

Townshend had found that if a strong electric field acts on a gas at low pressure, any ions generated in the gas by an external agency are set in motion by the electric field and under proper conditions produce fresh ions by collision with the gas molecules.

Rutherford and Geiger devised a simple piece of apparatus, which depended on this discovery of Townshend's, and were able to magnify to any degree the effect of an alpha-particle's 2000 collisions.

The apparatus worked in this way ; when the source of the alpha-particles is placed near the opening in the cylinder, the electrometer needle does not move uniformly, but at intervals. Each throw is a discharge by a single alpha-particle increased several thousand times. If a sheet of note-paper stops the rays, the needle rests. The interval between the times of entrance of a particle is not uniform. However, the alpha-particle emission is according to the law of probability. The interval between the particles is greater or less than the average ; thus by plotting the probability curve the number of alpha-particles per minute can be determined and from this can be calculated the total number expelled from a given weight of radium. The charge carried by each alpha-particle having been determined, the total charge carried by the alpha-particle in one gramme of radium can be found.

Rutherford and Geiger used alpha-particles from uranium, radium, thorium, and actinium. The number of alpha-particles per known area was ascertained. Thirty-four thousand million alpha-particles were found to be expelled per second from the radium present in one gramme in equilibrium. From other data it was found that radium, radium-A, and radium-C each expels the same number of alpha-particles per second when in equilibrium. To bring this down to ordinary figures, 136,000 alpha-particles are expelled per second from one-thousandth of a gramme of radium.

This apparatus remains for all time as a technical feat of the highest order. In fact Rutherford and Geiger had ' in principle counted the number of molecules in a cubic

centimetre of gas just as one can count the number of marbles in a box ! ' In fact " it is a matter of extraordinary interest that we are now able to detect by electrical methods a *single atom of matter* and so determine directly, with a minimum of assumption, the magnitude of some of the most important quantities of radio-active phenomena," said Rutherford.

From their data Rutherford and Geiger determined the charge on the alpha-particle as being $9 \cdot 3 \times 10^{-10}$ electrostatic units. It was now possible to settle once and for all the identity of the alpha-particle.

Other investigators had determined the charge on the hydrogen ion as being about $3 \cdot 5 \times 10^{-10}$ e.s.u. Indicating this by ' e ' it can be seen from the results that the alpha-particle carries a charge of between 2e and 3e. In other words it carries between 2 and 3 times the charge of a hydrogen ion.

The half-period of radium is, by Boltwood's direct measurement, 2000 years. If we assume that each atom of radium emits one alpha-particle, and that the charge on the hydrogen atom is $4 \cdot 1 \times 10^{-10}$ e.s.u. and we suppose that the heating effect of radium is a measure of the kinetic energy of the alpha-particle, then the charge on the alpha-particle is calculated as $9 \cdot 1 \times 10^{-10}$ e.s.u., which, it will be seen, is close to the experimental value obtained above.

Thus he concluded that the unit charge, e, is not very different from E/2, where E is the charge on the alpha-particle. If that is so, the alpha-particle carries twice the unit charge, or a neutral alpha-particle is a helium atom.

He did not hesitate to point out that it seemed rather contradictory that helium, an inert gas incapable of forming any compound whatsoever with any other element or elements, should be capable of having two charges. However, he suggested that as the alpha-particle plunges through molecules at great speed it must itself be ionized by collision. If two electrons are removed in this way, the double positive charge is explained.

Rutherford was now able to make numerous calculations and obtain considerable radio-active data. For instance, the ratio of the charge to the mass for the hydrogen atom e/m is $2 \cdot 88 \times 10^{-14}$ e.s.u. and e is $4 \cdot 65 \times 10^{-10}$, e.s.u., which means

that the mass of the hydrogen atom is $1{\cdot}61 \times 10^{-24}$ grammes and that there are $2{\cdot}72 \times 10^{-23}$ atoms in one gramme of hydrogen and $2{\cdot}72 \times 10^{-19}$ molecules per cc., in any gas at normal pressure and temperature. Again, the rate of production of helium from radium is 188 cubic millimetres per year. Thus the volume of emanation is $1{\cdot}25 \times 10^{-6}$ cubic millimetres per second. This he found was approximately the calculated volume and that the period of transformation of radium is not 2000 years, but 1750. As a further confirmation he found that the calculated heating effect of radium was 113 gramme calories per hour as against the experimental heating effect of 111 gramme calories per hour.

"It must be concluded," said Rutherford, "that the alpha-particle is a helium atom, that the atoms of the known radio-active elements are in part at least constituted of helium atoms, which are liberated at definite stages during disintegration."

Though the implications of these results seemed apparent Rutherford was not quite content. He wanted to obtain the same results by direct experiment. He felt this course necessary because he and Geiger had found a fundamental result which his intuition told him was to throw great light on radio-activity. Commenting on this work Boltwood wrote to Rutherford: 'These are quite up to the top-notch of your own standard and I think the best since the Bakerian lecture period which, in my opinion, can never be beaten. That Bakerian lecture is going down through history as a classic, and every time I turn to it I am comforted with the thought that I possess a copy.'

Rutherford, at the meeting of the British Association for the Advancement of Science in 1907, spoke on the constitution of the atom.

He regarded the electron as having come to stay, and although at that moment it was impossible to decide whether, when set free by radio-activity, it came from the outer circle or from the inner core of the atom, the kinetic view in opposition to Kelvin's static view gave an explanation of the velocity of the beta-rays, in other words, that the electron in the atom was moving about in it in some way.

Where and how the electron moved was by no means definite, but Rutherford's statement showed that he was

already in opposition to the older scientists as represented by Lord Kelvin.

At this meeting Lord Kelvin said that it seemed to him impossible that differences of grouping of atoms all equal or similar should suffice to explain all the differences, chemical, and other properties between the great numbers of substances then commonly called chemical elements. The impossibility of the transmutation of one element into another Lord Kelvin declared to be absolutely certain.

Sir Oliver Lodge hit the nail on the head when he said that the real difficulty in solving the nature of the atom lay in their ignorance of the nature of the positive particle. In opposition to Lord Kelvin's view, Rutherford stated that a gain of electrons produces permanent change in matter, because no profound change had been discovered to take place when an atom lost electrons.

Lord Kelvin, using one of his beloved mechanical illustrations, described the atom as a big gun loaded with an explosive shell. The firing of the shell did not, he said, cause the destruction of the gun, but the electron changed its nature in a way analogous to the bursting of the shell on explosion.

Lord Rayleigh (R. J. Strutt) made the very important contribution that the relation between helium and radium in minerals might not be due to radio-activity, but to the radium that they contained, since they were always together in the same proportions.

Next Rutherford and Geiger showed that the scintillations observed on the zinc sulphide screen of the spinthariscope are equal to the number of alpha-particles falling upon it. It follows from this that each alpha-particle produces a scintillation, and they pointed out that the electrical method of ionization by collision can be extended widely, and, under good conditions, it should be possible to detect a single beta-particle or electron, and consequently count the number of beta-particles expelled from a radio-active substance.

In this same year, 1908, Rutherford had the good fortune to be lent, through the generosity of the Vienna Academy of Sciences, a radium preparation containing 250 mgm. of radium, a large amount for those days. Rutherford made

a solution of it and drew off the emanation as it was required. Rutherford had radium emanation on tap. Using this, he made experiments to purify emanation. He tested the purity of the emanation by using the spectroscope, and made accurate measurements of the wave-lengths of many of the spectrum lines which had not previously been determined.

At the meeting of the British Association, 1908, Rutherford discussed the possibility of the spaces 178, 216, and 260 in the Mendeleef table being filled. He said that radon (emanation) had an atomic weight of 222, but that it might easily be 216, because of the possibility of its throwing off two alpha-particles. With the other elements only one alpha-particle was thrown off at a time, and for the 260 space it was highly improbable that there was an element higher than uranium ; in other words, uranium, the heaviest of all elements, was definitely that last element in the table, and there was little chance of a heavier one being discovered.

At the same meeting a scientist propounded the view that the scattering or deflection of the beta-particle was not an important factor, though his recent experiments showed that some scattering is present when beta-particles are absorbed or pass through a medium. Years later we will see he was mistaken in his prophecy.

For two years or so there had been a little argument between Rutherford and Sir William Ramsay about neon. Ramsay insisted that neon was given off with helium when the emanation was in water. Rutherford insisted that as a result of the experiments he had carried out he had never found the inert gas associated with radio-activity.

Rutherford described his experimental work with neon, showing that the amount of neon in 1/15 of a cubic centimetre of air readily gave the neon spectrum. Neon is one of the rare inert gases that compose the atmosphere, occurring to the extent of one part in 120,000 and the amount present in 1/15 of a cubic centimetre is therefore about one two-millionth of a cubic centimetre ! Rutherford attributed Ramsay's assumption that neon was formed by the action of emanation on water to a slight leakage due to air dissolved in the water during the experiment, and claimed that when air is excluded no neon is formed. Ramsay was not satisfied and upheld his experiments, and the question rose

at two or three later meetings of the British Association. In the end, however, Rutherford was shown to be right.

In November, 1908, the new theory that the alpha-particle was a sign of violent atomic explosion, in which fragments of the atom were ejected at high speed, was generally accepted ; but there was still lack of direct proof that the alpha-particle was a helium atom, and Rutherford and Geiger showed by an extremely simple method that the alpha-particle was identical with the helium atom.

Rutherford knew that the alpha-particle moved with tremendous speed and penetrated thin paper, and he knew that it would pass through very thin glass, though the walls of an ordinary tube would stop its flight. He intended to trap the particles and examine them by the spectroscope, by which he would have definite proof that helium could be obtained from accumulated alpha-particles, quite independently of the active matter from which they were expelled.

Radium emanation was taken as the source of alpha-particles, but the task of constructing the apparatus proved very difficult. Hundreds of tubes were broken in the attempt and many varieties of glass were tried until finally they constructed a double tube, one tube being sealed inside the other. The inner tube of very thin glass was filled with a large quantity of emanation and was then sealed inside the outer tube, the space between the two being carefully exhausted. After forty-eight hours this space was examined, and though only alpha-particles could penetrate the walls, the spectrum examination showed unmistakable signs of helium gas in the vacuum. The experiment was repeated many times, and always with the same result. The alpha-particles had passed through the thin walls of the tube-captured electrons, and had become atoms of helium. This proved directly that on gaining electrons the alpha-particle became an atom of helium ; that the alpha-particle was a positively charged atom of helium of mass 4.

This proof enabled the family of radio-elements to be distinguished by atomic weights. Rutherford and Geiger, knowing the position of an element in the series, could calculate, also knowing the number of alpha-particles

ejected to reach the position, the atomic weight of the element.

In the succession of products there occur several rayless products, and beta-rays products, and it could now be assumed that it was most improbable that the atomic weights of the radio-active elements changed without the explusion of an alpha-particle.

For example, when the known range of the alpha-particle from uranium, and the ionization it produces are compared with the radium associated with it, there is no doubt that the uranium atom expels two alpha-particles to one from the radium atom.

The atomic weight of uranium is 238·5. If two alpha-particles are expelled then uranium X of atomic weight 230·5 is formed, and, if from this, by an internal rearrangement a beta-ray is expelled then ionium of atomic weight 230·5 is formed. Ionium loses an alpha-particle, giving radium 226·5, another loss of an alpha-particle forms emanation (radon) 222·5, then radium-A 218·5, followed by radium-B 218·5, radium-C 214·5, and radium-D-E-, and -F all 210·5, finally, radium-G (polonium) 206·5.

The calculated weight is in good agreement with the experimental. Polonium is 206·5, and lead 206·9, suggesting that Boltwood's assumption that lead is the end of the radio-active succession, might be correct.

The thorium series was not brought into this scheme at the time, because it was not definitely known how many alpha-particles were ejected from it; but all this leads to the experimental proof of the correctness of the atomic hypothesis concerning the discrete structure of matter.

In 1909 the British Association went to Winnipeg for its annual meeting, and there master and pupil were presidents, Sir J. J. Thomson being the President of the Association, and Professor Ernest Rutherford being chosen President of Section A, Physics and Mathematics. Rutherford opened his presidential address in terms which showed his attachment to Canada.

". . . I feel myself in the presence of old friends, for the greater part of what may be called my scientific life has been spent in Canada, and I owe much to this country for the unusual facilities and opportunity for research so

liberally provided by one of her great universities. Canada may well regard with pride her universities, which have made such liberal provision for teaching and research in pure and applied science. . . .

" After seeing the splendid home for physical science recently erected by the University of Toronto, and the older but no less serviceable and admirably equipped laboratories of the McGill University, one cannot but feel that Canada has recognized in a striking manner the great value attached to teaching research in physical science. In this case as in other branches of knowledge, Canada has made notable contributions in the past, and we confidently anticipate that this is but an earnest of what will be accomplished in the future."

Surveying the fields ahead : " There is," said Rutherford, " much to be done as to the actual constitution of the electron and the part it plays in atomic structure. The atom consists of a number of positive and negative particles or masses held in equilibrium by electrical forces, but it is difficult to assign relative importance to the roles played by the carriers of positive and negative electricity. . . .

" It is not known whether the mass of the atom is due to electrons or other moving charges, or whether a type of mass quite distinct from electrical mass exists. There will be a delay until clearer knowledge of the character and structure of positive electricity and its relations to the electron is known.

" There are two roles for the electron," he said, " a satellite lightly attached and an integral constituent of the interior structure of the atom. The first plays a part in the combination to form molecules and in the spectrum of the element ; the latter is released by atomic explosion."

He gave another suggestion for the structure of the atom, saying that because of the fixed velocity of the alpha-particle from any element, it might move in a rapid orbital movement around the atom, but he pointed out that there was no definite evidence on this point. Then he suggested that because helium was always a product of the disintegration, when a product of less atomic weight was formed, the radioactive elements might be built up of helium atoms. . . .

There is no doubt, Rutherford argued, that considering

the huge energy of the alpha-particle and the small amount of its energy used up in ionizing, that the particle passed through atoms or rather the sphere of action of the atom lying in its path. There was no time for the atom to get out of its way, and thus the old dictum that 'two bodies could not occupy the same space' no longer held good in the case of atoms of matter if they were moving at sufficient speed.

"*Careful study of effects produced by the alpha-particle and beta-particles,*" said Rutherford, "*will doubtless throw much light on the constitution of the atom itself.* The work already done shows that the character of absorption of radiations is intimately connected with the atomic weights of the elements and their position in the periodic table. The most striking effect is the *scattering of beta-particles and deflections from their rectilinear path by encounters.*

"Geiger shows that the scattering of alpha-particles is very marked and is so great that a *small fraction have their velocity reversed in direction and emerge again on the same side* of the screen.

"The conclusion is unavoidable," said Rutherford, "that *the atom is the seat of an intense electric field,* for otherwise it would be impossible to change the direction of the particle in passing over such a minute distance as the diameter of a molecule."

Rutherford concluded his address by unconsciously indicating his great mind and the modesty with which he considered his achievements—achievements which are now considered as the fundamentals of modern physics and chemistry.

"In conclusion," he said, "I should like to emphasize the simplicity and directness of the methods of attack upon atomic problems opened up by recent discoveries."

Again those words 'simplicity' and 'directness'; the keynotes of Rutherford's power and success.

"As we have seen," he went on, "not only is it a simple matter, for example, to count the number of alpha-particles by scintillations produced on a zinc sulphide screen, but it is possible to examine directly the deflection of an individual particle in passing through a magnetic or an electric field, and to determine the deviation of each particle from a recti-

linear path due to encounter with molecules of matter. We can determine directly the mass of each alpha-particle, its charge, and its velocity, and can deduce at once the number of atoms present in a given weight of any known kind of matter. In the light of these and similar direct deductions based on the minimum amount of assumptions the physicists have, I think, some justification for their faith that they are building on the solid rock of fact and not, as are so solemnly warned by some of our brothers, on the shifting sands of imaginative hypothesis."

Every inch of the path Rutherford trod was solid, and he would progress no further unless sure of his ground. Had Rutherford ever allowed himself to be carried away by his imagination—and one can see in the fascination of his task how great the temptation was—the progress of modern physical science would have been delayed immeasurably. Not for an instant would Rutherford build on 'the shifting sands of hypothesis.' Hypothesis had its uses, but had to be kept sternly in its right place. For Rutherford facts came first, hypothesis always second.

CHAPTER VII

THE SECOND GREAT DISCOVERY

'Moseley had the spirit and courage of the true pioneer of science, coupled with great original ability and powers of work. It is rare in the history of science that so young a man has achieved so much.'

RUTHERFORD in 1925.

ALTHOUGH Rutherford carried on with his investigations into alpha-particles with unflagging zeal, he found time to turn his attention to other matters, and there was scarcely a branch of research that did not benefit from his interest.

A discussion by Rutherford on the properties of the radio-active element polonium, provides an excellent example of the importance attached to the 'half-period.'

Polonium is one of the transition elements produced during the transformation of the uranium-radium series. During his work in Canada, Rutherford showed that the element is actually a product of radium itself. Radium goes to emanation, and then gives the series radium-A, -B, -C, -D, -E, and -F, radium-F being identical with polonium obtained from radio-active minerals. Radium emanation decays in a tube to a mixture of radium-D, -E, and -F, and thus the amount of polonium in any radio-active substance can be easily calculated.

An equilibrium exists between radium and radium-F, the same number of alpha-particles being emitted per second from each. The half-life of polonium is 140 days, while for radium it is 1700 years. Therefore, polonium breaks up 5000 times faster than radium. So the amount of polonium in any mineral containing radium is 1/5000 of the amount of radium present. Thus 1000 kilogrammes of pitch-blende, containing 50% of uranium, has 170 milligrammes of

radium. From this it can be seen that the weight of polonium is just 1/30th of a milligramme. In fact, several tons would be required for 1/10th of a milligramme of polonium, a quantity comparable to a grain of sand.

Since polonium decays 5000 times faster, its activity, weight for weight, with radium should be 5000 times greater, while radium emanation, with a half-life of just under four days, has an activity 200,000 times that of radium, and the activity of radium-A, with a period of only four minutes, is 400 million times greater.

In the meantime, another great question was pressing forward for solution. During all these years of work on radio-activity there had been no international standard by which results from one laboratory could be compared with those from another. The only standards with anything like approaching international use were those used by Rutherford and Boltwood, which had been adopted by a number of English, Continental, and American workers.

To find a way out of the tangle, and largely owing to Rutherford's energy and enthusiasm, the International Congress of Radiology and Electricity, held in Brussels in 1910, appointed a committee to investigate this matter, and Rutherford read a report on the desirability of establishing an international radium standard.

He pointed out that the radium standards used in several important European laboratories had a difference of 20 per cent between them. He said that the work in radio-activity had reached a stage where it was possible to measure with considerable accuracy and precision a number of magnitudes connected with radium, mentioning as examples the volume of emanation, the heating effect, the rate of production of helium and the rate of emission of the alpha- and beta-particles. The values of each of these quantities, he said, depended on the accuracy of the radium standard in which the results were expressed.

It was obvious that results from two laboratories could not be compared to corroborate results if they were measured by standards which differed considerably and by unknown amounts.

As a result of Rutherford's report a special international committee was appointed to report on the best means to be

adopted for arriving at an international standard, the committee containing such famous people as Mme Curie, Debierne, Rutherford, Soddy, Hahn, Geitel, Meyer, Schweidler, Eve, and Boltwood.

Mme Curie agreed to prepare a radium standard containing about 20 milligrammes of radium in an enclosed tube, and the committee agreed to reimburse the expenses, as a result of which the standard would become the property of the International Congress and be under its control.

The standard was soon prepared, and laboratories prepared standards to compare with it. At the same time certain Governments became interested and acquired accurate standards to use as bases for the standardization of radium in their own laboratorics and that sold commerically. Within a short time Germany passed a law forbidding the sale of radium unless it had been compared with the Government's standard.

The committee also considered the formation of sub-standards for small quantities of radium and emanation.

Another suggestion put forward was that a certain quantity of radium should be known as the 'Curie,' in honour of Mon. Curie, who was the tragic victim of a street accident in April, 1906. This suggestion was acted upon, and the Curie became the unit to express the quantity or mass of emanation in equilibrium with one gramme of radium.

The question of the nomenclature of the radio-active series was discussed, an important business. Although the system in being was not by any means ideal, it was decided to make no change, since any advantage that would accrue by a more systematic nomenclature would be counter-balanced by the confusion caused by changes in name. It was decided to use numerals for derivatives of a definite element, e.g. radium-C ; derivatives : radium-C′, radium-C″, etc.

Another Rutherford motion called attention to the undesirability of individual workers assuming the right to give new and fancy names to well-known substances, thus adding to the confusion, and suggested that the discovery of an element did not give the discoverer the right to give it a particular name or to name it after himself.

The 'half-period' was defined as being the period in which a radio-active element decreases by half, and the terms 'induced' or 'excited' activity were abandoned and 'active deposit' decided on in its place, since the usual reference is to radio-active matter itself and not to the radiations.

Thus, the need for a definite standard which had been growing more and more acute as radio-active elements increased, was satisfied.

Nowadays the suggestions and decisions of this committee are taken for granted; so much so that it is barely realized what confusion there would have been without them. Seeming trifles, these things are almost as important as a fundamental discovery.

The work at Manchester was now concerned with the atom, which Rutherford intended to bombard, and needing a projectile for this purpose, he decided to use the alpha-particle. To a very great degree the method owed its origin to Lenard. He noted that when cathode particles of sufficient velocity were directed against a sheet of aluminium, by far the most of them would travel through thousands of atoms without any noticeable effect, though a small percentage were deflected from their courses at various angles, while a still smaller quantity of them rebounded. Lenard had arrived at the assumption that the atom was not a solid structure, as had been supposed, but was mainly composed of empty space through which the particles flew without meeting any obstacle.

This meant that it might be possible to compress matter to such an extent that a ton of steel would occupy the space of only a few cubic centimetres. It is thought to-day that in some of the hottest stars matter actually exists in this concentrated form.

The experiments of Geiger and Marsden had shown that the alpha-particles rebounded on being shot at a thin sheet of matter in the proportion of one in eight thousand. Rutherford found that the amount of rebound increased as the foil was increased in thickness until a constant value was obtained. The fraction of one in eight thousand, deflected or 'scattered,' through angles of over 90° was much greater than was to be expected from the experiments of Geiger in 1908.

Rutherford first came to the conclusion that the electrical fields in the atom were not of sufficient energy to deflect a projectile containing so much energy as the alpha-particle when it struck one atom alone. The large deflections observed were due, he said, to the combined deflection of the many atoms it met in its path.

The question was: why was a casual alpha-particle deflected? Rutherford carefully measured the angles, and he finally concluded that the deflection of the alpha-particle through a large angle was due to a single atomic encounter. It followed that it was necessary to suppose that the atom was the seat of an intense electrical field, and Rutherford suggested a simple structure of the atom which provided such a field. He supposed that the positive charge associated with the atom was concentrated into a minute centre or nucleus, and that the compensating negative charge was distributed over a sphere or radius comparable with the radius of the atom. The central charge behaved as a point charge, as did the negative electron. A point has position but no magnitude. Thus the central charge behaved as if its charge was concentrated in a point in the centre of the minute nucleus.

Then one day Rutherford, in the best of spirits, came into Geiger's room and told him that he knew now what the atom looked like, and how to explain the large deflections for the alpha-particle.

Next came that memorable meeting of the Manchester Literary and Philosophical Society in 1911, at which Rutherford in the presence of all the members in the laboratory gave his account of the constitution of the atom, backed by Geiger's new experimental evidence. Rutherford's words made a profound impression.

Rutherford marshalled his evidence as follows:

When a radio-active action explodes, the two new atoms are hurled apart through their surroundings, solid, liquid, or gas, in lines very nearly straight.

It has been proved that the helium atom pursues its rectilinear motion, not by pushing the atoms it meets in its path nor by pursuing a path straight as a whole, containing deviations to avoid atoms, but by going through all it met.

Therefore, two atoms could be, so to speak, in the same place at the same instant.

And the colliding atoms could not, therefore, be mutually unpenetrable if they were of the size usually assigned to them.

Therefore *they must resemble miniature solar systems and not solid spheres.*

From his own enquiries by his own methods he had found, Rutherford said, that the helium atom was occasionally scattered from a straight line path, that the change in direction must be violent, and that one solar system sweeping through another could not suffer a deflection unless the two central suns were sufficiently close to one another to be thus turned aside from their original path.

Therefore, he concluded that the analogy of the solar system must be complete, down to the provision of a central sun. That sun must be, he said, a positive nucleus containing almost all the mass of the atom, but occupying a very small volume of the whole of the atom, while the electrons were a cloud in the outer field.

The nuclear theory had been expressed in a surprisingly complete form and it is difficult to exaggerate its influence on pure and applied physics and chemistry since 1911, and it will rank for ever as *the* finest of all Rutherford's contributions to physics.

The germ of this work was the fact that in the counting experiments with Geiger, Rutherford had noticed that traces of residual gas in the long tube down which the alpha-particles passed, had influenced the counter.

Commenting on this Geiger writes: 'The genius of Rutherford had seized upon an apparently unimportant detail and transformed it into a clue to the problem of the inner structure of the atom.'

The formulation of this theory depicts one of the greatest qualities of Rutherford's genius—his gift for seizing upon the vital point. And in this case, what *was* the point? Just the discrepancy between Geiger's measurements of the scattering of the alpha-particle through small angles and the apparently trivial observation that a small fraction of the particles which fell on a thin foil rebounded. It was the

typical sequence to the ' Ruthfordian ' way of picking out problems.

In an appreciation of Rutherford in the *Observer* Sir Richard Gregory said :

' Two thousand years ago Lucretius, the Epicurean, preserved for us in immortal verse the atomic theory imagined by Democritus and other early Greek philosophers. This comprehensive but vague assumption is recorded with respect by the historians of science, but it had no definite influence on scientific progress until it was developed by Dalton. Rutherford's theory of atomic structure was not created by him purely by introspection, but as a means of unravelling a tangled skein of observations of radio-active and similar phenomena.'

CHAPTER VIII

THE THREE MUSKETEERS OF SCIENCE—RUTHERFORD—MOSELEY—BOHR

RUTHERFORD was most fortunate to find two inspired scientists to collaborate with him at the moment when he needed such men to help him to consolidate his atomic theory: Henry Gwyn Jeffreys Moseley and Niels Bohr.

Rutherford undoubtedly owed much to their genius and he was the first to acknowledge the big debt.

Moseley had been finishing his academic career at Trinity College, Oxford, while Rutherford was carrying out the researches on the atom. Before taking his degree Moseley visited Manchester and discussed with Rutherford the possibility of his entering the Manchester laboratory to carry out researches. He asked Rutherford to suggest a line of research for him. Rutherford suggested three lines, the first being his own first love—radio-activity. This Moseley chose and returned to Oxford, very happy in the thought of undertaking research under the great physicist.

Moseley was the son of the distinguished zoologist, Professor H. N. Moseley, who died in 1891. Young Moseley had a very original and active mind, and having obtained a first class in Mathematical Moderations and Honours in Natural Science, he went to Manchester to take up the appointment of lecturer and demonstrator in the Physics Department of the University.

Rutherford had carefully mapped out the preliminary work which was to show him the calibre of his new colleague, and he soon found, as he said himself, that 'Moseley was one of the rare examples of a man who was a born investigator. He rapidly acquired the technique of experiment . . . his undoubted originality and marked capacity as an

investigator was recognized ungrudgingly by his co-workers in the laboratory, while his cheerfulness and willingness to help in all possible ways, endeared him to all his colleagues.'

Moseley's first work was to determine the average number of beta-particles emitted during the transformation of an atom of radium-B to radium-C, a very difficult and important piece of work, and he announced at a Royal Society meeting that every atom of radium produced but one electron. This was a discovery of great importance, and Sir William Crookes, who was president of the Royal Society at the time, congratulated Moseley on the clear and fluent presentation of such an intricate problem.

It then occurred to Moseley that the potential to which radium could be charged in a high vacuum by the escape of its own beta-particles should be determined. This, again, was a very ticklish problem. Radium loses negative electrons and continues to do so ; it should, if there were no possibility of its losing its charges, become more and more positively charged until a high potential is reached. Moseley was a very fine experimenter ; he managed to achieve so high a state of exhaustion that a small quantity of radio-active matter retained itself at a potential of more than 100,000 volts for several weeks.

No sooner had he solved these problems than a piece of very important news came to hand. Professor Max von Laue, of the University of Zurich, had discovered that X-rays were diffracted in their passage through a crystal. X-rays have a wave-length about 1/10,000th that of light, so small, in fact, that the ordinary substances such as glass or a polished metal surface will not reflect or diffract them.

Simultaneously, the Braggs, father and son, were working along the same lines in Leeds. They used the discovery that in crystals the atoms are spaced regularly and close enough together to act as a diffraction grating to the X-rays to determine the inner structure of crystals of pure salts. The X-rays were allowed to pass through very thin sections of crystals and then photographed. The Braggs found that crystals were made up of regularly spaced rows of atoms about one-millionth of a millimetre apart.

Moseley's interest was attracted by this work at Leeds. With his close friend, Darwin, he photographed the diffracted

X-rays, from a crystal of rock salt and confirmed the work of the Braggs. Then he extended it, by passing the X-rays produced by the electrons striking a positively charged platinum plate or anti-cathode, and mapping out for the first time the spectrum characteristic of the X-ray.

Finding that he now had more work on his hands than he could cope with, Moseley resigned his lectureship in order to be able to devote the whole of his energies to research. He was awarded the John Harling Fellowship.

Meanwhile, Rutherford had suggested that the charge on the nucleus of every element ought to be proportional to the atomic weight of the element.

X-rays were known to be of two kinds, one of which was merely due to the stoppage of electrons, the other being sent out from the anti-cathode of a Crooke's tube and depending on the metal or metals of which the anti-cathode was composed.

Rutherford wondered if these facts could be used in any way. He conferred with Moseley. As a result, Moseley decided to examine the X-ray spectra of a large number of different elements and compare the photographs he obtained, so determining the nature of the charge on their nuclei. He was going to find whether the spectrum was in any way connected with the atomic number of the element, when the elements were arranged in the increasing order of atomic weights.

For fifteen hours a day Moseley worked in the laboratory. He fixed a plate to the anti-cathode of a Crookes tube and excited it with a bombardment of electrons. The plate gave out its characteristic X-rays.

In his first paper on the subject Moseley said that he had examined the spectra of a group of elements of atomic weights between calcium and zinc and had found that a spectrum consisting of two strong lines was emitted by each of these elements.

Various problems, he said, had presented themselves. In some cases the X-rays from a particular element were so easily absorbed by the glass of the X-ray tube that a special window of very thin glass had to be built. This glass would not stand the pressure of the atmosphere on the evacuated interior of the tube, but the difficulty was got over by covering

the glass with goldbeater's skin. Even then the high vacua he needed often resulted in rupture of the window, making the work delicate and tedious ; but Moseley had inexhaustible patience.

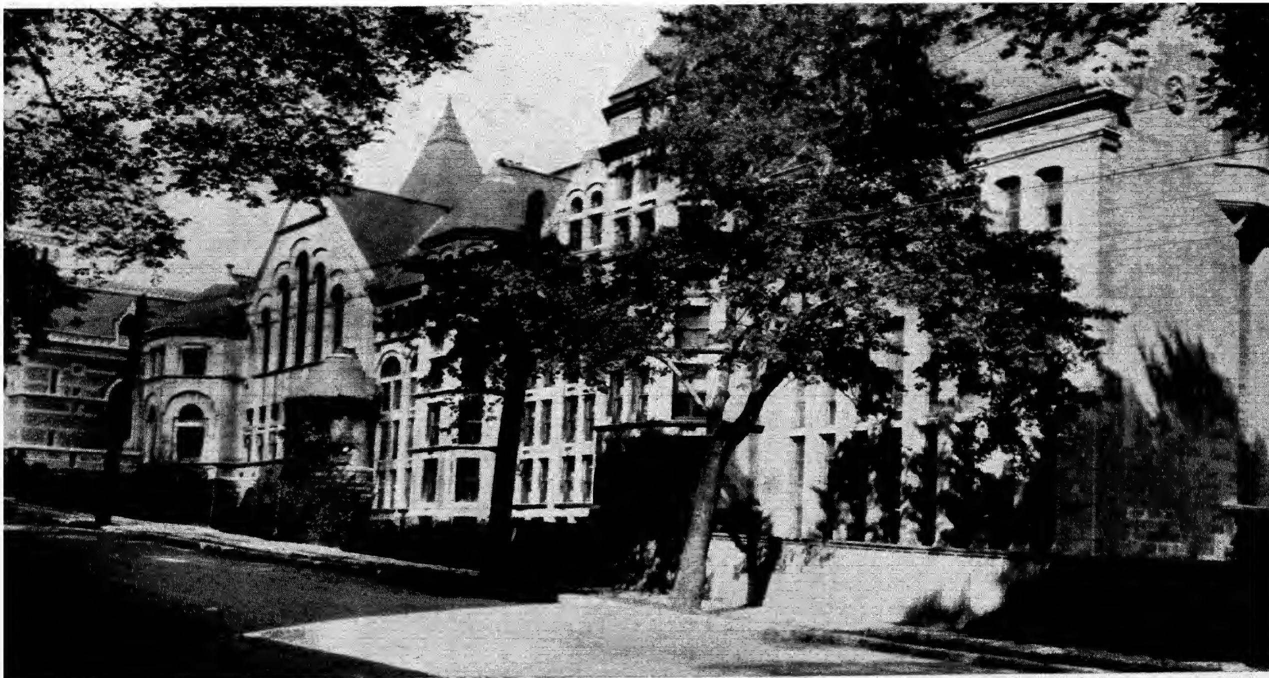
After the comparatively short period of six months Moseley published his results in two papers. He had found that the frequency of the two strong lines in each spectrum was proportional to the square of a whole number which varied by unity in passing from one element to the next.

After a systematic study of the spectrums of thirty-eight of the solid elements he found that the heavier the element the shorter and more penetrating were the X-rays produced. On plotting a graph of the atomic numbers of the elements against the inverse square roots of these X-ray frequencies he discovered that the elements arranged themselves in a straight line in the exact order of their atomic weights, and that the frequency of a given line in the X-ray spectra varied in definite jumps in passing from one element to another. This is 'Moseley's staircase.'

Early in 1914 Moseley went back to Oxford to study these results, and came to the conclusion that there is a fundamental quantity in the atom which increased by regular steps as we pass from one element to the next, the seat of this quantity being the nucleus. By observing the gaps in the regular steps he predicted that between aluminium and gold only three unknown elements could exist.

The scheme of the elements had now been determined showing the place of each element in the table, indicating the positions of unknown elements and disproving the would-be existence of certain elements, in astral bodies, thought to be between hydrogen and lithium.

The importance of Moseley's discovery was instantly recognized. Professor Urbain, of the University of Paris, an eminent authority on rare elements, was puzzled by a number of elements found in certain ores, and was not quite certain how many rare elements were present. He consulted Moseley. Moseley was able to tell him what elements were present and also their *relative amounts*. Urbain went back to Paris with a considerable amount of data to work on, that, in the ordinary way, would have taken



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months to obtain. On working out his results, he proved Moseley's data correct.

In the summer of 1914, Moseley and his mother embarked for the meeting of the British Association in Australia, and Rutherford and many other famous men of science travelled over too. Their arrival in Australia coincided with the outbreak of the Great War. But science came first.

In the discussion on the atom, opened by Rutherford, Moseley showed that all the elements fell into the order of increasing atomic as dictated by their X-ray spectra. Each element possessed a definite number in the scheme starting with hydrogen as No. 1 to uranium No. 92. There are two exceptions.

For many years chemists had been puzzled by the fact that in the Mendeleef periodic table argon has an atomic weight of 39·95 and potassium 39·1, and if placed in the order of atomic weights, we get chlorine, potassium, argon, putting potassium among the inert gases group and argon, an inert gas, in the alkaline metals group, which is anything but inert. If placed in order of chemical properties, then we have chlorine, argon, potassium in their right groups, but in their seemingly wrong order. Moseley showed that the X-ray frequency gave the order : chlorine, argon, potassium, the seemingly natural one.

At the conclusion of the meeting Moseley rushed home and offered his services to the Government. He could have worked in a war-research laboratory but this he refused to do. Putting aside all thought of continuing the investigations in which he was so vitally interested and refusing a sheltered job at home, he insisted on joining the fighting forces and was given a commission in the Royal Engineers. Then he became Signals Officer to the 38th Brigade of the First Army and left for the Dardanelles on 13 June 1915. He took part in the severe fighting at the landing on 6 and 8 August, and on the 10th, while telephoning to his Division at a moment when the Turks were attacking on a flank only 200 yards away, was shot dead by a bullet through the head.

By the throwing away of a young life in such a wasteful fashion the world sustained a loss the full extent of which can never be gauged, for who knows to what brilliant heights

Moseley might have risen? What was felt by his death can best be appreciated by the tributes of those who knew him and his work. An officer in his company said: "In him the Brigade has lost a remarkably capable signalling officer and a good friend; to him his work always came first, and he never let the smallest detail pass unnoticed."

Millikan said: "In a research which is destined to rank as one of the dozen most brilliant . . . in the history of science, a young man twenty-six years old threw open the windows through which we can glimpse the sub-atomic world with a definiteness and certainty never dreamt of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history."

And Rutherford, who felt the loss greatly, in a tribute published in *Nature*, said: "Scientific men of this country have viewed with mingled feelings of pride and apprehensions the enlistment in the armies of so many of our most promising men of science, with pride for their ready and ungrudging response to their country's call, and with apprehension of irreparable loss to science.

"These forebodings have only too promptly been realized by the death in action of Henry Gwyn Jeffreys Moseley, 2nd lieutenant in the Royal Engineers, at the age of twenty-seven. . . .

"Moseley's fame rests securely on this fine series of investigations, and his remarkable record of four brief years' investigations led those who knew him best to prophesy for him a brilliant career. There can be no doubt that his proof that the properties of an element are defined by its atomic number is a discovery of great and far-reaching importance, . . . and is likely to stand out as one of the great landmarks in the growth of our knowledge of the constitution of atoms.

"Our regret for the untimely end of Moseley is all the more poignant that we can but recognize that his services would have been far more useful to his country in one of the numerous fields of scientific inquiry rendered necessary by the war than by exposure to the chances of a Turkish bullet."

* * *

In the year 1912 a young mathematician, Niels Bohr, was preparing for his degree of Doctor of Philosophy, in the University of Copenhagen, when he decided to go to Cambridge to study for a time under J. J. Thomson, and in the spring of the same year he went to Manchester to work under Rutherford. A man of theory was going to work with a man of experiment.

Bohr was an exceedingly hard worker; for weeks he practically lived in Rutherford's laboratory, it being said by his colleagues that he only emerged when it was necessary 'to come up to breathe.'

In the summer of 1912 he published some results on the constitution of the atom.

Using Rutherford's conception of the atom as a miniature solar system he boldly postulated the idea of a dynamic hydrogen atom, the simplest of atoms having just a single electron outside its nucleus. Throwing away classical mechanics he used Planck's Quantum Theory.

This revolutionary theory put forward by Max Planck, maintained that energy is not emitted in a continuous manner, but in very minute bundles called 'quanta'; in other words, energy is atomic in structure.

Bohr drew a mental picture of the lonely electron of hydrogen revolving in an elliptical orbit round the nucleus until it happened to be disturbed by some outside force such as cathode rays, X-rays, or heat. When so disturbed, said Bohr, the electron jumps from one orbit to another closer to the nucleus, and in doing so, causes some form of radiant energy to be produced. The jump is indicated by a distinct line in the spectrum of hydrogen.

Using this method of attack he very cleverly explained mathematically the line spectrum of hydrogen. He determined the amount of energy required to move a single electron from one orbit to another. He went further and explained that the spectrum of hydrogen is so complex because every sample of hydrogen gas used during any experiment consists of a large number of atoms with their orbital electron in different states of equilibrium.

Bohr had determined the position of the electron of hydrogen, its spectrum, and the character of its orbit. The other more complex atoms still defy analysis. He had

made use of all the theories and discoveries known at the time and thereby postulated a fairly probable explanation of the phenomena, showing that there is comparatively more empty space in an atom than there is in the solar system.

For example : if the atom were to be enlarged to the size of Shell-Mex House, a very small marble circling it many million times a second would represent the electron, and somewhere in the centre of the House a billiard-ball would represent the nucleus.

Though Rutherford distrusted theorizers, he had the greatest regard for Bohr, holding him in such great esteem that when a scientist asked him one evening, whilst a visitor at his house, if the origin of the beta-particles accompanying radioactive disintegration was to be traced to the nucleus or not, Rutherford replied that he did not know and suggested asking Bohr. To-day their atom is known as the Rutherford-Bohr model.

The experimental results of Moseley and the theory of Bohr were due to the firm foundation Rutherford had provided for their building.

A new piece of apparatus was now at Rutherford's disposal, the improved Wilson Cloud Chamber. C. T. R. Wilson, at Cambridge, had answered J. J. Thomson's question : 'Can you photograph the electron ?'

Twenty-five years later Rutherford said : "To this period belongs the development of an instrument which to my mind is the most original and wonderful in scientific history—I refer to the 'cloud' or 'expansion chamber' of C. T. R. Wilson. I had the good fortune to be present in the Cavendish Laboratory when Wilson was examining the formation of water-drops in damp, dust-free air by sudden adiabetic expansion of the gas. When X-rays were discovered Wilson at once showed that the ions produced by the X-rays in their passage through the gas acted as nuclei for the condensation of water-vapour upon them under certain conditions of saturation. A cloud of visible water-drops was formed and in a sense each ion was rendered visible by the water-drop formed round it.

"The next important advance was made in 1912 when Wilson devised the modern type of expansion chamber and

showed that the tracks of individual alpha-particles and fast electrons were rendered visible by a trail formed on the ions liberated by the passage of these flying particles through the gas. It was a wonderful advance to be able to see, so to speak, the details of the adventures of these particles in their flight through the gas. Anyone with imagination who has seen the beautiful, stereoscopic photographs of the trails of swift alpha-particles, protons, or electrons, cannot but marvel at the perfection of detail with which their short but strenuous lives are recorded. The cloud chamber has proved an invaluable aid to research in many directions. This instrument provides in a sense a final court of appeal in which the experimenter may place his trust. I cannot imagine anyone with the most vivid scientific imagination who could have predicted the possibility of an instrument endowed with such unique powers and potentialities."

The Rutherford-Bohr model provided many new problems for the 'family' at Manchester which included among others C. G. Darwin, J. Chadwick, H. Geiger, H. R. Robinson, J. M. Nutall, E. Marsden, D. C. Florance, J. A. Gray, R. W. Boyle, A. Kovarik, the American H. B. Boltwood, who came over for a year in 1911, Niels Bohr, and H. G. J. Moseley. A formidable array of men who have since become world-famous.

Geiger and Marsden carried out experiments which verified the numerical deductions made by Rutherford on his nuclear theory. These experiments provided a fairly conclusive proof of the existence of the nuclear atom.

In 1911 Rutherford took part in a unique conference. Mr. Ernest Solvay of Brussels invited, at his own expense and as his guests, those famous European scientists who were interested in theories of radiation and molecular theory in general. Again, at his own expense, he published the proceedings of the discussions.

The novel '*conseil scientifique*' met at the end of October 1911 at the Hôtel Metropole, Brussels, where, in that informal atmosphere so dear to Rutherford, the many problems of physics were discussed.

Those present included H. A. Lorentz, Kammerlingh Onnes, W. Nernst, Max Planck, Rubens, Sommerfeld, W. Wien, Warburg, Brillouin, Mme Curie, J. H. Jeans,

Perrin, Poincare. Einstein, Goldschmidt, Lindemann, De Broglie, and Rutherford.

The conference brought out the lack of knowledge prevailing on the constitution of radio-active matter, and Rutherford's explanation of the alpha- and beta-rays from the radio-active nucleus threw a new light on the whole problem of the constitution of the atom. This question had seemed so remote, said De Broglie, that no one had dared think of it in the first ten years of the twentieth century. In fact, it was so obscure that even at this conference, when the scientists were asked what picture one could form of the emission of refracting rays from radio-active substances, the specialists were forced to reveal their own ignorance of the subject.

But Rutherford was far better placed than they were and he was able to make a decisive attack on this problem because he could designate a definite model to the atom from experimental facts.

When the conference was over, Mr. Solvay invited all his guests to meet again in 1913.

In February 1912 Rutherford and Robinson published results on the origin of the beta-rays from radio-active substances. He said that he had found from study of radio-active transformations that each atom of matter in disintegrating, emits one alpha-particle . . . but in many cases of transformation beta- and gamma-rays are emitted, and from analogy it would be expected that one beta-ray would be emitted for the transformation of each atom.

"The experiments of Baeyer, Hahn, Danysz, and Miss Meetner have shown that the emission of beta-rays from radio-active substances is, in most cases, a very complicated phenomenon. . . ." By observing in a vacuum the deflection of a thin pencil of beta-rays in a magnetic field, and allowing them to fall on a photographic plate, a number of sharply marked bands are observed, indicating that the rays consist of a number of homogeneous rays, each of a different velocity. Radium-B and -C give 27 sets.

On analysing the results it was found that the beta-particle is initially liberated within the atom and endowed with a certain speed, but in escaping from the atom it may pass through two or more regions in which a quantity of energy

is abstracted. The number of these units of energy abstracted will vary from atom to atom, each individual atom probably giving rise to only a few types of the beta-rays observed. This explains the complexity.

It is interesting to note that Rutherford was guided by a concept analogous to that of Bohr's 'energy levels' of 1914. Rutherford had found further evidence connecting the energy values of gamma-rays emitted from radium, with the energy of the beta-particle required to excite the characteristic radiation in the atoms of radium-B and -C, and he said that it was of great theoretical importance to examine with the greatest care the nature of the emission of beta-rays from all the known radio-active substances, for such an examination promised to throw a great deal of light on the interior of the atom.

In the year 1913 three interesting meetings took place. Shortly after the first Solvay conference Mr. Solvay generously put up the sum of a million francs for the formation of an International Physical Institute, part of the fund to be devoted to the assistance of researchers in physics and chemistry, part to defray the cost of an occasional scientific conference between men of all nations. The result was a second International Conference (Conseil International de Physique Solvay) at Brussels from 27 to 31 October 1913. The general subject of discussion included the structure of the atom. These conferences were proving very useful to the informal exchange of views, and Rutherford in particular enjoyed them, since he was able to exchange views with various authorities and obtain news of progress in other branches of physics and chemistry.

The other two meetings were the British Association and the famous Literary and Philosophical Society of Manchester. At both Rutherford's subject was the constitution of the atom.

At the first, Rutherford described his solar conception which consisted of a charged nucleus of minute dimensions in which most of the mass is concentrated, surrounded by a distribution of electrons.

At the second meeting Rutherford added that the nucleus was positively charged and was surrounded by a distribution of negative electrons sufficient to make the atom electrically

neutral. He said that this type had been conceived in order to explain the fact that the swift alpha-particle was scattered in traversing matter and was greatly deflected as the result of a single encounter with another atom. The number of electrons was, he said, equal to about half the numerical value of the atomic weight.

Rutherford also mentioned Geiger and Marsden's confirmatory scattering experiments, over a million cases agreeing with his theory!

Mention was made of a fact discovered by Marsden that when alpha-particles were shot into hydrogen, some of the nuclei obtained such a great velocity from impact with the particles that they travelled at least three times the distance of the alpha-particle in the same gas. This indicated that the alpha-particle, though heavier than the hydrogen atom, possessed a very considerable amount of energy which it was able to transfer to the hydrogen nuclei in the form of energy of motion.

Rutherford also said that the charge on the nucleus, which determined the physical and chemical properties of the atom, was likely to prove a much more fundamental constant than the atomic weight. In March 1913 a revised edition of Rutherford's book on radio-activity was published under the title *Radioactive Substances and their Radiations*. The book was a very fine survey of the work that had been done in radio-activity and in particular of the great strides that had been taken since the appearance of his previous book in 1906.

It showed, however, that it was still not definitely known whether atomic transformation ever occurred without the emission of any ionizing radiation, though the steadily diminishing proportion of products regarded as rayless suggested that it was not so. However, it showed that knowledge of radio-activity had grown and that something was already known of the nature of the final products of radio-active transformation, while there was strong indirect evidence leading to the supposition that lead was the final product in the case of the radium series. Direct evidence was still being awaited. The work which Rutherford had recently been engaged on showed that branch series of descent were in existence and that there was a probability

that thorium had two lines of descent, with, consequently, at least two final products.

In a review of Rutherford's book, R. H. Strutt (Lord Rayleigh) focused attention on to the fundamentals of the other's work; he wrote: 'The principle focus at present are the beta- and gamma-rays. The discovery by Baeyer, Hahn, and Marsden that beta-rays from certain bodies can be resolved by magnetic fields into line spectra has given the lead needed, and order and definiteness begin in the hopelessly involved.'

By the end of 1913 some of Bohr's conclusions had been published and the great advance in knowledge concerning the constitution of the atom is best displayed by quoting a reply given by Rutherford in *Nature* to a letter by Soddy in the same journal:

'In a letter to this journal last week Mr. Soddy has discussed the bearing of my theory of the nucleus atom of radio-active phenomena and seems to be under the impression that I hold the view that the nucleus must consist entirely of positive electricity.

'As a matter of fact, I have not discussed in any particular detail the question of the constitution of the nucleus beyond the statement that it must have a *resultant* positive charge. There appears to me no doubt that the alpha-particle does arise from the nucleus, and I have thought for some time that the evidence points to the conclusion that the beta-particle has a *similar origin.* This particle has been discussed in an early paper by Bohr. The strongest evidence in support of this view is, to my mind:

'1. That the beta-particle, like the alpha-ray transformations, is independent of physical or chemical changes.

'2. That the energy emitted in the form of beta- and gamma-rays by the transformation of an atom of radium-C is much greater than could be expected to be stored up in the external electric system.

'At the same time I think it very likely that a considerable fraction of the beta-rays which are expelled from radio-active substances arise from external electrons. This, however, is probably a secondary effect resulting from the primary expulsion of beta-particles from the nucleus.

'The original suggestion of Van der Brock that the *charge on the nucleus is equal to the atomic number* and *not* half the atomic weight seems to me very promising. The idea has already been used by Bohr in his theory of the constitution of the atom.

'It would appear that the charge on the nucleus is the fundamental constant which determines the physical and chemical properties of the atom, while the atomic weight, although appreciably following the order of the nucleus charge, is probably a complicated function of the latter, depending on the detailed structure of the nucleus.'

What a step from Dalton's atom!

With the assistance of E. N. Da C. Anrade he devised a most ingenious arrangement of slit and crystal to obtain a reasonable angle of reflection for examining gamma-radiations. The reflected radiation was examined by a photographic method after precautions had been taken to prevent marked effects by the beta-rays. They examined the rays from emanations of radium-B and -C.

The gamma-ray emission was found to be complex and when the wave-lengths were determined it was discovered that they formed a well-defined series.

From these measurements they obtained confirmation of the veracity of the photo-electric law connecting the gamma-rays with beta-ray spectra.

In August 1914 came the fateful Australian meeting of the British Association.

Rutherford summed up his pre-war work at Manchester.

First of all he directed attention to the recent accumulation of evidence of the independent existence of the chemical atom. "It was no longer," he said, "a mere hypothesis, introduced to explain the laws of chemical combination, and we were able to determine the actual mass of an atom within a small percentage."

The atomic character of negative electricity had been well established, and the negative electron, however produced, was always found carrying a definite charge.

"We have," said Rutherford, "unfortunately not the same certainty with regard to the behaviour of the positive electricity, for it cannot be obtained except associated with a mass comparable to the hydrogen atom. In J. J. Thom-

son's model of the atom the positive electricity was supposed, for mathematical reasons, to be distributed through a large sphere with the negative corpuscles moving inside it. This hypothesis played a useful part in indicating the possible lines of advance ; but it does not fit in with more recent discussions, which points to a concentrated positive nucleus.

"In C. T. R. Wilson's photographs of the tracks of the alpha-particles through a gas many sudden bends in the paths are observed. In order to account for these deflections it is found necessary to believe that there is a concentrated nucleus atom (having a certain number of units of charge) in which the main part of the mass resides ; outside this, there is a number of electrons. The whole dimensions of the nucleus are very small indeed compared with the distance of the outer electrons. From the scattering experiments it appears that the law of force right up to the nucleus is the inverse square law. No other formula would give accordance with observations.

"The radius of the nucleus is of the order of 10^{-12} (1 million-millionth) cm., in the case of gold, and for a lighter element it is still smaller . . . the number of electrons (outside the nucleus) is about half the atomic weight. There is now fairly good evidence that, if the elements are numbered serially in order of atomic weights, the numbers actually express the charge on the nucleus. The rate of vibration of the inner parts of the nucleus can now be measured by means of the characteristic X-rays emitted. Each substance has two strong lines in its X-ray spectra, and as we pass from element to element in order of the atomic weights, the frequencies of these change by regular jumps. H. G. J. Moseley has investigated all the known elements in this way, and he has even been able to show at what point elements are now missing, because at such points the X-ray frequencies made a double jump. In this way he has found that between aluminium and gold only four elements are now missing.

"It is deduced from these considerations that there is something more fundamental than atomic weight, viz. the charge on the nucleus and that this is the main factor which controls the frequency or the interior vibrations, the mass having only slight importance.

"There are certain elements with identical chemical properties, but different atomic weights; thus radium-B 214 and lead 207 are chemically inseparable and have the same gamma-ray structure. It is quite clear that some new conception is required to explain how the atoms, having the structure we have supposed, can hold together. Niels Bohr has faced the difficulty by bringing in the idea of the quantum. At all events there is something going on which is inexplicable by the older mechanics."

Most of those present supported Rutherford and suggested one or two difficulties which would have to be got out of the way before the solar conception of the atom could be fully proved.

Then, while the British Association had been calmly and logically discussing Nature, in another part of the world passionate and illogical forces were getting to work. Europe was plunged into war. Theory and experiment, scientific fact and hypothesis went by the board. Research and investigation had to be put aside, for who could carry on calmly and undisturbed at such work when even the peace of the laboratories was being shaken by the thunder of the guns?

CHAPTER IX

THE THIRD GREAT DISCOVERY

THE position which Rutherford was rapidly attaining in the scientific world can be gauged by the honours that were crowded upon him. On 10 December 1908 he was awarded the Nobel Prize for Chemistry, given in consideration of his researches into radio-activity. In the same year, on 29 June, the centenary of the foundation of the Physio-Medical Society of Vienna, he was made a corresponding member of the Society. In May the Turin Academy of Sciences conferred upon him the Bressa Prize of 9600 lire (£384). In commemoration of a recent visit of King Edward VII and Queen Alexandra to open the new buildings of the University of Birmingham, a special congregation was held on 20 October 1909, and amongst those honoured at the occasion was Rutherford, who was made an Honorary Doctor of Law.

At the recommendation of the National Academy of Sciences of the United States, the trustees of Columbia University awarded Rutherford the Barnard Medal for the period of five years ending in 1909, for meritorious service to science, special mention being made of his investigations into the phenomenon of radio-active materials. Rutherford was the fourth holder since the medal's inception, his predecessors being the most brilliant pioneer scientists of their time. They were: 1895, Lord Rayleigh and Sir William Ramsay (jointly); 1900, Professor W. C. von Röntgen; 1905, M. Henri Becquerel.

On 20 November 1911 the Munich Academy of Sciences elected Rutherford, together with Professor Perkin, Professor of Organic Chemistry at Rutherford's University, corresponding members.

Finally, King George V conferred on Rutherford the

honour of knighthood in the New Year's Honours of 1914. He was then forty-three years old.

The outbreak of hostilities caused the happy 'family' to disperse, resulting in Rutherford's carrying on with a much depleted staff. It was not long before the Government asked him to give his services in the cause of the nation. In July 1915 he was appointed to the Admiralty Board of Invention in Research (B.I.R.). He also served on the Panel of the Board and on the sub-committee dealing with that most pressing need of the time, detection and location of submarines.

Instead of tracing alpha-particles he was now to trace submarines. It required a great effort to make the necessary mental change, but he was equal to it and accomplished it with his usual energy.

The laboratory at Manchester was turned upside down. A great tank appeared in the ground floor research laboratory. Research was to be prosecuted in another little-known branch of science—under-water acoustics.

A research station was opened at Aberdour on the Firth of Forth in November 1915. A constant stream of apparatus and ideas to be tried out on ships and submarines at this station came from Manchester. In spite of all this Rutherford managed to continue a great deal of University work and made frequent visits to London and, which he enjoyed most of all, to Aberdour. The sea air and his work on the ships on the Forth acted as a tonic to him in these strenuous times.

In fact he was so much in demand that after six months' work he decided to take a few days' rest, but was followed by a deluge of letters from the B.I.R.

He was instrumental in obtaining Professor W. H. Bragg to take charge of the station. The staff welcomed Rutherford's frequent visits with much joy. He was always brimming over with suggestions and sometimes impatient at delays due to red-tape.

In 1917 the station was moved to Parkeston Quay at Harwich. Here work was continued on hydrophones and a longevian piezzo-electric method of detection was developed and improved.

During this period he visited the U.S.A. in conjunction

with the mission of English and French engineers, chemists and physicists who placed the anti-submarine plans of Great Britain before the leading scientists of the U.S.A. This enabled America to further development of these plans, using the vast resources at her disposal.

It is interesting to note, as Rutherford once stated, that when the war was over a re-survey was made of all scientific methods which could have been used in this work, and it was found that none had been overlooked. He added the tribute that such devices would certainly have been of little use but for the intrepid courage and skill of British seamen.

On 13 March 1917 the committee of the Athenæum Club elected as members Sir Ernest Rutherford, F.R.S., and Sir William Peterson, K.C.M.G., LL.D., Principal of McGill University, under the provisions of Rule II, which empowers the annual election of a 'certain number of persons of distinguished eminence in science, literature, the arts, or for public services.'

On 9 July 1918 Rutherford was elected foreign member of the Royal Academy 'dei Lincei,' Rome.

The Great War period was not entirely given up to war work. In spite of the many calls made upon his time, Rutherford managed to carry out a large amount of research on his own account and his much depleted staff did their full share. Scientifically, they were interesting years, seeing the development of isotopes and the work leading to another of Rutherford's fundamental discoveries.

In 1912 it had been found that a positive ray beam, composed of neon ions, could, by a magnetic field, be separated into two parts indicating that neon consisted of two groups of particles of different mass. In other words all the neon atoms were not identical in mass.

The wonderful sequences of the radio-active transformation series were causing a difficulty. There were a large number of elements whose discovery was difficult to reconcile with the periodic table. The existing vacancies were eligible for only a few of the new radio-active elements, viz. radium, polonium, and actinium. What was to become of the remaining elements? These radio-active elements in all cases possessed chemical properties identical to those of

known elements. They differed only in the cases of atomic weight and radio-active properties. Therefore the majority of the radio-active elements were to be described as isotopes.

The fundamental discovery, which brought order to the seemingly chaotic conditions prevailing among the radio-active products, was the fact that the alpha-particle, when expelled from an atom, caused a shift of two places to the left in the table by altering the mass, whilst the removal of a beta-particle caused a shift of one place to the right by altering the atomic number.

Using the concept discovery of the nuclear atom, Soddy, after considering these facts, came to the conclusion that isotopes have the same net nuclear charge, though the gross number of positive and negative charges differs.

The isotopes are usually chemically inseparable from each other.

Lead provided an important indication of the positive existence of isotopes. The atomic weight of lead varied according to the mineral from which it was extracted. Lead from uranium ores had an atomic weight of 206·05, while in the case of lead from thorite it was 207·67.

Said Soddy: "We are returning to the view of the Greek philosophers and the alchemists that elements are qualities, not constituents."

In 1918 Soddy made the startling declaration: "Every one of the conceptions which associated the atom with the chemical element now has to be modified."

"Atoms of different chemical elements may have," he said, "the same atomic weight; but those which the chemist and spectroscopist regarded as the same element might have different atomic weights which made the attempts to define the atom during this period most difficult, because even though the atoms may all have the same weight, the element may nevertheless be an unresolvable mixture of fundamentally different isobaric isotopes."

Thus the complete apparent identity might conceal differences which, when revealed, would be of paramount importance. The goal that inspired the search for the homogeneous constituent of which the material world was composed was known to be like infinity, approachable rather than attainable.

Soddy's pronouncements rather 'annoyed' certain quarters of the worlds of physics and chemistry, but the many discoveries made in the separation of the radio-active elements completely verified Soddy's views.

Radio-active change gave a new means of analysis for which, outside radio-active elements, there was no equivalent.

But the homogeneity of the chemical element had vanished.

Further developments in the recognition of isotopes were now imminent, and much work was accomplished when Aston perfected his mass-spectograph.

In 1915 E. J. Evans, who was responsible for much of the spectroscopic work in the Manchester laboratory, proved definitely that the Pickering series, a series of lines first observed in some atoms, was to be ascribed to helium and not hydrogen as had been assumed before Bohr put forward his theory of the constitution of the atom.

Bohr himself suggested such an experiment, in a draft of a paper he sent to Rutherford in 1913, as a test of his theory.

Other important work was carried out, particularly on the branching of the radio-active series, the chemistry of the radio-active substances, the heating effect of radon, while Guy and Florance examined the gamma-ray scattering from lead and provided from their results the first slight indication of the Compton Effect.

Though these researches were steps towards that nebulous goal—the full understanding of the process of radio-activity and the constitution of the atom—the alpha-particle was still of paramount importance.

This minute projectile starts out from the atom, for its travels, with a velocity 20,000 times that of a rifle bullet or 19,000 kilometres per second. Its energy is tremendous. An ounce of helium moving at the same speed as a particle from radium-C has energy of motion equivalent to 10,000 tons of solid shot projected at the rate of one kilometre per second.

Thus the alpha-particle is powerful enough to penetrate deeply into the structure of all atoms. If the mass of the alpha-particle and that of the atom were known, the distribution of velocity after collision could be calculated. The alpha-particle and helium atom collision gave the

expectation that the energy transferred to the helium atom would give it a speed approaching that of the alpha-particle.

Marsden made experimental observations of the results of collisions between alpha-particles and gold and hydrogen.

The results for speed of the hydrogen atom in the experiment were found to agree with that calculated when the ordinary laws of impact were applied to the collision. Thus the atoms could be accepted in the case of scattering experiments, as behaving as two perfectly elastic spheres of masses proportional to the masses of the atoms.

The distance they travelled after collision before being brought to rest depended on both the mass and the charge carried by the recoil atom.

If the recoil atom had a double charge after collision, it was to be expected that the range was one-quarter of that of a recoil atom with a single charge. Therefore, one could not expect to detect the presence of any recoil atom having two charges beyond the range of the alpha-particle, but one could calculate any recoil atom if its mass approached a figure less than that of oxygen, while a single charged recoil atom could be detected beyond the range of an alpha-particle.

Thus it was thought to be possible to detect the presence of such singly charged ions if they existed, after completely stopping the alpha-particle by a suitable thickness of absorbing material.

This method had good advantage. The number of swift recoil atoms were remote in comparison to the number of alpha-particles present, and it could not be hoped to detect them in the presence of the much more numerous alpha-particles.

In order to calculate the number of recoil atoms scattered through any given angle from the direction of flight of the alpha-particle, it was necessary, in addition, to make an assumption as to the constitution of the atoms and as to the nature and magnitude of the forces involved in collision.

For example, an alpha-particle collided with an atom of gold atomic number 79, the nuclei behaved like point charges and repelled according to the inverse square law. Geiger and Marsden counted the proportion of alpha-particles from radium-C having a direct collision, that is, the number which were turned through 180° as they approached

the closest possible distance to the gold nucleus. The number increased for oblique collisions. At an angle of 50° the number of alpha-particles scattered through the angle was 200,000 times the number scattered through 180°. This was in close accord with theory. The inverse square law held for distances of the magnitude of $3{\cdot}6 \times 10^{-12}$ $\frac{4}{1,000,000,000,000}$ cm. from the nucleus.

Marsden first designed a simple piece of apparatus for the detection of the hydrogen particles after collision, using as his source a glass tube of radium. Rutherford improved upon it and used a disc covered with a source of emanation which gave an intense supply of particles and, unlike Marsden's supply, unaffected by any glass.

The box-like apparatus was filled with dry hydrogen at normal temperature and pressure. The hydrogen atoms striking a zinc sulphide screen at one end were counted; the beta-ray illumination was removed by bending the beta-rays away from the screen by a magnetic field. It was assumed that for the distances involved in the collision the alpha-particle and the hydrogen nucleus could be regarded as point charges, and that oblique impacts should occur much more often than head-on collisions. Consequently the stream of hydrogen atoms set in motion would contain atoms whose velocity varied from zero to the maximum produced by direct collision. The slow velocity atoms would greatly preponderate, and the number of scintillations observed should fall off rapidly when absorbing screens were placed in the path of the rays close to the zinc sulphide screen.

Instead, a most astonishing effect was observed. When the alpha-particle collided with a hydrogen atom, the number of swift hydrogen atoms resulting remained unchanged when screens representing absorptions from 9 to 19 cm. of air were placed in their path. Then, the number fell steadily. At 28 cm. no scintillations were observed.

Thus the swift hydrogen atoms were behaving similarly to a stream of alpha-particles of range 28 cm. They were travelling mainly in the direction that the colliding alpha-particle travelled and their velocities confined within narrow limits.

By using alpha-particles of different velocities it was found

that the speed of the swift hydrogen particle varied accordingly as was to be expected from the theory of point charges. This indicated that unexpected changes were taking place concerning the forces involved in the collisions when the nuclei of the colliding atoms approached each other closer than a certain distance.

In addition to these peculiarities the number of hydrogen atoms was greatly in excess of the number to be expected on the simple theory. For example, for the swiftest alpha-particle, the number which was able to travel a distance equivalent to 19 cm. of air was more than thirty times greater than the calculated value.

It should be borne in mind that the production of a high-speed hydrogen atom by an alpha-particle was an exceedingly rare occurrence. Under the conditions of the experiment the number of hydrogen atoms was seldom more than 1/30,000 of the number of alpha-particles.

Each alpha-particle passed through the structure of 10,000 hydrogen molecules in traversing one centimetre of hydrogen at atmospheric pressure, and only 1 alpha-particle in 100,000 of these produced a high-speed hydrogen atom; so that in 1000 million collisions with molecules of hydrogen, the alpha-particle on the average approached only once close enough to the centre of the nucleus to give rise to a swift hydrogen atom.

From the number of hydrogen atoms observed it was calculated that the alpha-particles must be fired within a perpendicular distance of one 4 million millionths cm. from the centre of the hydrogen molecules in order to set it in swift motion. This was a distance less than the diameter of an electron—720 million millionths cm. The general results were those to be expected if the alpha-particle behaved like a charged disc of radius about the diameter of an electron, travelling with its plane perpendicular to the direction of motion.

It was therefore clear that for distances of the order of the diameter of the electron the alpha-particle no longer behaved like a point charge.

These results in no way invalidated the nucleus theory as used for explaining the scattering of alpha-particles by heavy atoms, but showed, as was expected, that the theory

broke down when close approach was made to the nucleus structure.

Since little was then known about the structure of the alpha-particle, Rutherford could only speculate as to its structure and the distribution of forces very close to it. He suggested that the alpha-particle of mass 4 be taken as consisting of four positively charged hydrogen nuclei and two negative electrons, and that the combination was about the size of the electron on the supposition that the hydrogen nucleus was of much smaller dimensions than the electron itself. The magnitude of forces between the hydrogen atom and alpha-particle in the collisions was enormous; an equivalent to 6 kilogrammes weight. Thus, it was to be expected that the structure of the alpha-particle would be deformed after such a fierce collision, with the result that the law of force underwent very marked changes in direction and magnitude for small changes in the distance between the two colliding nuclei. This was a reasonable explanation of the anomalous position created by the results due to the factors involved in the collisions.

The most surprising thing of all, though, was that in spite of the fierceness of the collision the helium nucleus escaped disruption. No evidence was found that it did so. The helium nucleus had proved itself to be extremely tough.

All elements of atomic mass less than 18 travelled beyond the range of the alpha-particle, provided they carried a single charge. In the case of helium collisions no long-range recoil atoms were found, indicating that after the recoil the helium atom carried a double charge. Similarly no certain evidence was obtained of long-range recoil atoms from lithium, boron, or beryllium. The difficulty in the case of bombarding solids was the removal of all traces of hydrogen or water vapour, which produce swift hydrogen atoms.

A special examination was made of recoil atoms in those from collisions with the gases oxygen and nitrogen. Bright scintillations were observed in both these gases about 2 cm. beyond the range of the alpha-particle. They were assumed to be due, presumably, to swift nitrogen and oxygen atoms carrying a single charge.

The corresponding range of the recoil atoms was about the same in oxygen, nitrogen, and carbon dioxide, though

theoretically, the nitrogen recoil atom should give a somewhat greater range than that of the oxygen atom.

The number of recoil atoms in nitrogen and oxygen and their absorption indicated that these atoms, like hydrogen atoms, were shot forward mainly in the direction of the alpha-particle. It was clear from the results that their nuclei could not be regarded as point charges for distances of the order of the diameter of the electron. Taking into account the close similarity of the effect produced by hydrogen and oxygen, and the greater repulsive forces between the nuclei in the latter case, it seemed probable that the abnormal forces in the case of oxygen manifested themselves at about twice the distances observed in the case of hydrogen.

In Marsden's preliminary experiments he found that the source of alpha-particles always gave rise to a number of scintillations on a zinc sulphide screen beyond the range of the alpha-particle. Rutherford had always found these natural scintillations present in the sources of radiation employed. The swift atoms producing these scintillations were deflected in a magnetic field and had about the same range and energy as the swift hydrogen atom. The number was usually small, and Rutherford found it difficult to decide definitely whether such atoms arose from the disintegration of the active matter or to the action of the alpha-particles on hydrogen occluded in the source.

These extraordinary long-range fast hydrogen nuclei appeared to Rutherford 'so pregnant with far-reaching implication' that he decided to obtain complete experimental data about them. Assisted only by Kay, a prince among laboratory stewards, he carried out the necessary experiments.

The source of radiation was placed in a box, exhausted of air, about 3 cm., from an opening in the end which was covered with a sheet of silver sufficient to stop the alpha-rays completely. The zinc sulphide screen was fixed outside, close to the silver plate. On introducing dry hydrogen or carbon dioxide into the box, the number of scintillations fell off in amount corresponding with the stopping power of the column of gas. An unexpected effect was observed on introducing dry air from the room. Instead of diminishing, the number of scintillations increased, and for an absorption

of 19 cm. of air the number was twice that observed when the box was exhausted. Thus it was clear that the alpha-particles in their passage through air gave rise to long-range scintillations which appeared to be of about the same brightness as hydrogen scintillations. This effect proved to be due to the presence of nitrogen. The number of scintillations was far too large to be accounted for by the presence of traces of hydrogen or water-vapour. The effect observed was equivalent to the number of hydrogen atoms produced by a mixture of hydrogen and oxygen at 6 cm. pressure.

It appeared that nitrogen was giving swift hydrogen atoms as the result of its collisions with alpha-particles.

That they definitely were hydrogen was verified by measuring the deflection of a pencil of the rays in magnetic and electric fields. The experiments were exceedingly difficult on account of the very small number of scintillations to be expected under the existing conditions.

Rutherford finally concluded that the long-range atoms arising from the collision of an alpha-particle with nitrogen were not nitrogen atoms, but charged atoms of hydrogen or atoms of mass 2. That being so, it was concluded that the nitrogen atom is disintegrated under the intense forces developed in a close collision with swift alpha-particles, and that the atom liberated formed a constitutional part of the nitrogen nucleus.

In other words, Rutherford had discovered *the means for producing artificial disintegration.*

It was now possible for man to control the disintegration of certain atoms.

It was suggested from radio-active data that the nitrogen nucleus of atomic mass 14 consisted of 3 helium nuclei of mass 4 and a hydrogen nuclei of mass 1 and of mass 2.

The suggestion put forward as an explanation of the phenomenon was that the effect in nitrogen arose through the hydrogen nuclei being outriders of the main nucleus of mass 12. The close approach of the alpha-particle led to the disruption of the bond of one of them with the central nucleus, and under favourable conditions the hydrogen atom would acquire a high velocity and be shot forward like a free hydrogen atom. Considering the great energy

of the particle, the close collision of an alpha-particle with a light atom seems to be the most likely agency to promote its disruption, and in view of the enormous intensity of the forces brought into play in such collisions it is not really so remarkable that the nitrogen atom should suffer disintegration, but it is remarkable that the alpha-particle itself escapes disruption.

Rutherford said : " The results on the whole suggest that if the alpha-particle or other similar projectiles of still greater energy were available for experiment, we might expect to break down the nucleus structure of many of the lighter elements."

From the day on which Thomson had discovered the electron as part of the atom, Rutherford had pondered on the nature of the remaining part. Now, by forceful entry he had learnt the secret ; by bombarding the inner citadel with the most powerful projectiles man has so far known, he had compelled it to surrender its mysteries to him. The interior of the atom was laid bare.

To have accomplished so much might have contented many men. On the strength of that work alone Rutherford's name was destined to live for ever. But it was not enough. Rutherford was possessed of an unquenchable thirst for knowledge and an undying energy for exploration. He determined to press on.

The work was not to be done at Manchester. Sir J. J. Thomson, finding the task of directing a laboratory and a great college too exacting, resigned from the chair of Cavendish Professor of Experimental Physics, and he who had been his student took his place.

Rutherford was known to speak with great pleasure and emotion about the prospect of his going to Cambridge, but at the same time he expressed a fear that the many duties connected with this central position in the realm of British Physics would not grant him the same opportunities for research as he had had at Manchester, but this was an unbounded fear.

On 3 April 1919 it was announced that Rutherford had been appointed to the Cavendish Chair of Experimental Physics.

CHAPTER X

THE HUMAN ALPHA-PARTICLE

SO far we have followed Rutherford's scientific career closely, as if his work were itself under a microscope ; but what of Rutherford the man ?

There have been scientists whose work has been of primary importance, but whose personality has left little mark. Their work overshadowed their personalities, blotting it out, as it were ; it is as if they had been machines, making no lasting ties of friendship when they lived and leaving no memories beyond their functioning powers behind.

Rutherford was, however, the very negation of the scientist of convention. In the chapters describing his youth stress was placed upon the intensely human aspect of the man ; that stress can be repeated, for throughout his career, and at every moment of his life, Rutherford never lost his humanity. There was a vital force in him sufficient to drive the great machine of his brain and keep his body at work at full pressure, yet leaving a reserve of energy which radiated round him to attract friends. Even the most casual observer could not miss the tremendous power of his eyes. They seemed to be animated by the whole dynamic force of a splendidly active and virile brain.

Only those who came into personal contact with Rutherford can realize how ably he mixed the scientist with the man, and how he carried personal charm into the laboratory. This large, bluff, shaggy man, who looked like a farmer and never lost his provincial accent, endeared himself to his juniors. It is significant of their regard for him that in the laboratory he was known as 'Papa,' and it was in a paternal way that he treated the young men beneath him. He had an irresistible sense of humour, would use humour to illustrate his points, shared jokes with all, and had the

kindliest way of helping others to overcome their difficulties and putting them right when they went wrong.

With students he was as the father of a family, and was very unconventional. When things were going right and new discoveries were coming out at the rate of about one a week, his footsteps as he strode along the corridors would be accompanied by a whistled tune recognizable as an attempt at 'Onward, Christian soldiers.' When things were not going quite so well, the well-known thump of the professor's feet was no less energetic, but the tune then would be 'Fight the Good Fight.'

He was fond of chaffing his young research students, and he had a loud and infectious laugh. On his own work he was a brilliant lecturer, and when questions and discussions followed, there were often remarkable exhibitions of wit and wisdom. His terse phrasing, his magnificent employment of slang, his remarkable analogies, and his chaff would keep his audiences rocking with laughter, but there was no playing to the gallery, no sophistication. In his own way, and with his manner of meeting men on an equal basis, he would make them understand a subject almost as well as he did himself. His manner was all the more enjoyable because there was no pose about it, no preparedness. It was natural and spontaneous, all part of his bigness.

Rutherford made it a habit to go round the whole laboratory once a day to have a word with each student. He had a remarkable way of remembering everything that he had previously said to each man and the difficulties each had encountered.

He found young research people indispensable to him, not only because it gave him better chances of working out a large number of problems, but also because, as he often said, the young students kept him young. Rutherford, in fact, remained not only young right to the end of his days, but even 'boyish.' His enthusiasm, energy, and gaiety never flagged. He said that in research he always felt as if he were a young man, and his ambition and curiosity never slackened. He detested the saying 'the good old days,' whether of physics or anything else, and he found that his young pupils made him keep in touch with up-to-date ideas. He would never oppose new theories,

as several other physicists did, simply because they were new.

Other scientists from various countries had only to meet Rutherford to fall under his spell, and the contacts he made were numerous. In 1911 Arrhenius visited him and spent about three weeks in Manchester at the time when Rutherford was convulsing the scientific world with new discoveries about the atom. Arrhenius was anxious to learn about the discoveries at first hand and spent the greater part of his time in the laboratory. He was fascinated by Rutherford and was amazed that one who had done so much in the laboratory could be so unbending, even so jolly, outside.

Another example of Rutherford's jollity comes from an experience when in Austria. In the summer of 1913 he, accompanied by his wife, went with his friend, Stefan Mayer, to Bad Ischel, where the three Viennese scientists, Hönigschmidt, Mache, and Schweidler, met him. Rutherford was very fond of motoring, and was one of the first to motor in England. He motored through Austria, and at Ischl, Boltwood, who was with him, bought a Tyrolese hat and wore it continually. This hat was a source of unending amusement to Rutherford.

They were trying to arrange a radiological conference in Vienna for 1915, but the war prevented the realization of the scheme. It did not, however, lessen the friendly relations between Rutherford and the Viennese physicists, and after the war Rutherford managed to solve for a period the financial difficulties of the Vienna Academy of Science.

As an organizer of the work at Manchester, Rutherford proved his ability, though in this he was likened by one of his contemporaries to a tribal leader rather than one who excels at the game of chess, and he had to be interested in his subject to show the ability he possessed. When organizing his students for radio-active research, he allotted to each man a task within his capacity and, if urging was necessary, urged him on in his own characteristic way. He had the power to create in his students intense belief in himself. When Rutherford said a thing could be done, then it could and had to be done. This spirit braced every man's courage and self-confidence, and Rutherford always preferred a man to work on his own ideas rather than to have just another

assistant working under his guidance. As soon as he discovered any originality in a pupil, he would do everything he could to develop it ; when failure produced periods of depression, ' Papa ' never failed to instil new hope. But he never excused blunders, and quickly ' put on the brake ' when he saw a young man likely to be carried away by too much optimism, as, for instance, in drawing premature conclusions from an experiment not thoroughly completed. His ' boys,' as he called them, soon learnt that his judgment was always reliable and to the point.

His fairness in acknowledging a pupil's ideas or originality bred a healthy spirit in the laboratory, and his personal kindness and goodwill gained the greatest affection which a pupil can have for a teacher. Throughout the career of anyone under him he took an interest in his doings, and many who later made great names for themselves owed much that they did to the encouragement and friendship extended to them by Rutherford at Manchester.

His influence was not confined to his own country ; his relations with the Curie family in Paris were intimate, and the presence of the Italian investigators who were welcomed to his laboratory led to keen appreciation by him of advances in radio-active research which were later made in Rome.

Rutherford detested any pose. In physics he had little use for mystical ideas, although it was often claimed that their origin lay in his own work. He would not argue, however, for his sense of physical reality was intuitive rather than reasoned. " Nature," he would say, " is not like that," referring to the mystical ideas.

Outside physics, too, his philosophy was expressed in actions rather than words. He distrusted subtlety, and he had no time for pessimism. Life was too good while there was work worth doing, and when work was done, he delighted in the pleasure of hard exercise, books, and the company of friends. Out of working hours, he felt that men should consort as equals, and for his own part, quite without self-consciousness, he never failed to convey that sense of equality. There was no calculated ' playing down.' To him age and eminence were simply irrelevant.

He could argue with a younger man, yet never have recourse to authority for the reinforcement of a weak case.

He could charm without any deliberation. If a first-term student happened shyly to state the view of some universally known matter, he would reply in all seriousness: "I am glad to hear you say that. It confirms what I have always thought." Such answers captivated his students.

On the other hand, he did not guard his words when he spoke of some academic pundit who seemed to him to be assuming as personal right the respect paid to his office. "He is like the Euclidean point," he would say, "having position without magnitude."

His rapid rise was attributable to two remarkable qualities not often found in men of genius in research, who usually possess great powers of concentration respecting their own work but shine with a very dim light outside the laboratory. In the first place, Rutherford was an enthusiastic teacher and lecturer, inspiring the hosts of students who clamoured to enter his laboratory; and in the second place, his common sense and worldly wisdom enabled him to tackle administrative problems with conspicuous success.

At Manchester he was a regular attendant and active worker on the Faculty of Science and the Senate. His facility for getting straight through the accessory details to seize on essential principles was used as earnestly in the problems of University control as in his research work. No one who saw him at a faculty meeting or at a meeting of the Board of Examiners would ever have guessed that between the meetings he was unravelling the great secrets of Nature, and doing this work quite clearly conscious of the greatness of the world he was opening up.

Like Newton, he seemed to form his judgments spontaneously. In his experimental work he had constantly a feeling about what he was to come up against before the quarry was in sight, so that he took the significant step at the right moment. There was no mistake. He could distinguish more easily than most men what was important, what trivial; neither time nor pains were wasted in following roads that led nowhere. "What is wanted for progress," he would often say, "are not seemingly clever or highly imaginative ideas about Nature, but the knack of finding, so as to say, God's idea of Nature."

Someone once said that "no one but a blockhead

researches except for fun," and Rutherford was one of the supreme examples of this. For him life was a thing he could never be sufficiently thankful for, a tremendous experience not to be spoiled in any way. " It's a great thing, life," he said. " I wouldn't have missed it for anything."

The work that he had been so far engaged on has been referred to as 'modern alchemy,' and, in fact, Rutherford had done what the early alchemists failed to do. He had shown that it was possible to produce small fragments of gold, though only by the transmutation of a more costly element, platinum. The gold produced was so small as to be neither visible nor weighable, but it existed, and he often coupled this with one of his favourite stories: that of an early alchemist.

One of our kings, he said, founded a company of alchemists to produce gold in large quantities, and with the 'gold' they made he instituted a new coin. But the king arranged matters so that it should not be circulated in England, considerately allowing it to be used over the border in Scotland and in France. The Scots promptly retaliated by refusing to allow the coin to enter their country, for there was strong evidence to the effect that the 'gold' was copper and mercury, giving the coin the noble colour of gold.

" As for the philosopher's stone," said Rutherford once, " men have searched for it for thousands of years, and radium comes as near to it as anything that has so far been found."

He was hostile to the assumption of the infallibility of scientific calculation. An applicant for a post on his staff once used this to advantage. To Rutherford's statement that he already had thirty workers under him, the would-be recruit replied that surely he could not calculate meticulously how far his funds would go. Rutherford liked the reply, and the man got the post.

The years from 1907 to 1914 were, perhaps, the greatest period of his life. A stream of papers on all aspects of radio-activity poured from his laboratory, nearly all of them of outstanding importance.

The successful completion of the main task of classical radio-active research greatly enhanced his fame, and a spirit of contentment prevailed in the laboratory. Of all Rutherford's spiritual children, none was more deeply

loved by him than the alpha-particle, and none requited his affection more generously.

Just as he detested posers did he mistrust men called 'clever.' He looked askance at those who wanted to build up science on purely deductive lines, and was fully convinced that the line of advance followed by him so successfully, based on the application of sound common-sense considerations to experimental observations of the right phenomena, was the most trustworthy road to progress. This deep conviction did not, however, prevent him from early recognizing the fundamental importance of ideas moving largely on deductive lines, put forward by Bohr shortly after the introduction of the conception of the nuclear atom. The union of Rutherford's nuclear concept with Bohr's ideas proved to be an immensely fruitful one, the importance of which even far exceeded Rutherford's first expectations. In later years Rutherford said of these days that they did not then fully realize what great times they were witnessing.

Of the days at Manchester Bohr himself said : " From the moment I was admitted into the group of students from different parts of the world working under Rutherford's guidance, he appeared to me to be the very incarnation of the spirit of research. Respect and admiration were words too poor to describe the way his pupils regarded the man whose discoveries were the basis of the whole development in which they were enthusiastically striving to partake.

" What we felt was rather a boundless trust in the soundness of his judgment, which, animated with his cheerfulness and goodwill, was the fertile soil from which even the smallest germ in our minds drew its force to grow and flourish. His simplicity and disregard of all external appearances perhaps never disclosed themselves more spontaneously than in discussions with his students, who were through his straightforwardness even tempted in youthful eagerness to forget with whom they were talking until, by some small remark, the point of which they often first fully understood after they had left him, they were reminded of the power and penetration of his insight.

" The stimulus Rutherford gave his pupils was, however, in no way limited to times of daily intercourse. When I returned to Denmark I pursued the line of work which I

had taken up in Manchester, and it was a most encouraging feeling to know that I could always count on his warm interest and invaluable advice. Indeed, I can hardly realize how, in the midst of all his work, he could find time and patience to answer in the kindest and most understanding way any letter with which a young man dared to augment his troubles.

"Especially close was our relationship during my stay for the first years of the Great War as lecturer in Manchester, and, when in times full of anxieties, he kept up the spirits of the small group left in the laboratory, and in the short moments of leisure from the great practical duties thrust upon him steadily went on preparing the road to new discoveries, which should soon lead to great results."

Stress has been laid on Rutherford's skill as an experimenter; yet most of his experiments were so simply conceived as to be easily understood by a layman. Their performance did not require a complicated piece of machinery, nor even exceptional experimental skill. But it is no exaggeration to say that such simple experiments, for example, as the discovery of the positive nucleus inside its cloud of electrons, or the method of producing artificial disintegrations by alpha-particle bombardment, were milestones in the world's knowledge of Nature.

The large and successful group of investigators round him learnt not only the principles and the methods of research, but also the necessity of endurance and steadiness, essential requirements of the man of science.

A young scientific worker aims at perfection and looks for some ideal to follow; this perfection, this ideal, was to be found in Rutherford's way of showing simplicity in what seemed intricate, of attaining with apparent ease what was thought unattainable, of putting aside every obstacle as if it were merely a shadow. His work was more than science; it was an immediate contact with Nature.

"To have Rutherford's approval," said a former student, "was a high reward for any worker in the domain of radioactivity. When Dansycz focused the magnetic spectrum of beta-rays and when Rosenblaum discovered the fine structure of alpha-rays, what an immense joy it was for them to receive Rutherford's letters of congratulation. If

such was the effect of the written word, no wonder so many wished to get near him. His ideas and personality attracted young research students, and his abilities as a teacher helped him to let each of his pupils develop his own character."

Of his days at Manchester Rutherford could justifiably have quoted the words of Newton : " For in those days I was in the prime of my age for invention, and minded philosophy more than at any time since."

CHAPTER XI

FIRST YEARS AT THE CAVENDISH

IN October 1919 Rutherford took over directorship of the Cavendish Laboratory from Sir J. J. Thomson, being the fourth of the brilliant series of directors. Clerk Maxwell and Lord Rayleigh had preceded J. J. Thomson.

Under Rutherford's guidance the Cavendish was destined to attain even greater fame. Considerable success accompanied his encouragement of the policy of allowing overseas and foreign students to be admitted to degrees. Usually half his students came from the Empire or the Continent, and particularly happy were the contacts made with students from Rome, which resulted in the founding of a group of research workers carrying on along Rutherford's lines at Rome. This policy of Rutherford's was of great advantage to the Empire, for there is scarcely a university overseas that has not at least one member of its staff a former student of the Cavendish Laboratory.

Rutherford continued J. J. Thomson's series of afternoon tea-parties, but one of the delightful features of life at Cambridge in those days was Rutherford's Sunday afternoon tea-parties at his own home. He consistently invited students from the laboratory, and if they would not talk he delighted to do so himself on a great diversity of subjects with energy and animation.

It has been said that the period between 1919 and 1931 was not very fruitful in the way of discoveries, but though little of a sensational character was announced, an enormous amount of spadework was done.

Quietly and unassumingly the firm foundations for the future were constructed.

Rutherford brought with him a great deal of apparatus from Manchester, including the Vienna radium, and so

with little delay he continued to pursue, with his characteristic energy, the path marked out by his work at Manchester. The nucleus was now admitted to the intimacy enjoyed by the alpha-particle, and experiments bearing on the nuclear structure were the main feature of the work.

The recognition of isotopes expanded and confirmed Rutherford's theory of the construction of the nucleus, but it did not entirely explain the fractions in atomic weights.

By November 1919 six isotopes of lead were already known, and they differed from one another either in atomic weight or radio-active properties.

The nucleus theory, as we have seen, explained isotopes simply. Rutherford said: "The proof of the presence of isotopes promises to open up a new and very fundamental field of chemical inquiry, which must inevitably exercise great influences on atomic weight determinations and also on our ideas of atomic construction."

Geiger and Marsden had shown by further scattering experiments that the resultant units of positive charge on the nucleus of an element is about equal to its atomic number. A simple example is the helium atom. It consists of a nucleus of mass 4, that is, four positive charges. With these charges are 2 electrons, while outside, in orbits, are another 2, making 4 in all to balance the 4 positive charges in the nucleus, in which way the atom is made electrically neutral. Therefore, the resultant *nucleus* charge is 4 positive charges plus 2 negative charges, giving a resultant positive charge of 2, which is the atomic number of helium.

Rutherford was asked to give the Royal Society Bakerian Lecture of 1920. He accepted, and chose for his subject the atom, and dealt with it in his usual brilliant manner.

He said: "The problem of the constitution of the atom divides itself naturally into two parts; one, the arrangement of the external electrons on which the ordinary chemical and physical properties of the atom depend, and the other, the constitution of the nucleus on which depend the mass of the element, the possibility of isotopes and radio-activity."

Rutherford discussed the forces at work in the atom. In the outer region around the nucleus the Coulomb law force held, but close to the nucleus Rutherford found a rapid change in the magnitude and direction of forces

which were, he said, probably in part connected with the deformation of the nucleus structure under the intense forces arising in a close collision. "Unless," he said, "the nuclei are very stable, it is to be anticipated that they would be deformed and possibly broken up as a result of a direct collision with swift alpha-particles."

Referring to his recent work on the disintegration of the nitrogen atom, he mentioned the new experiments which he had made to determine by a modified method the nature of the swift particles from the disintegration, by bending them in a strong magnetic field. He had found that the amount of deflection of these particles was the same as for those liberated from a mixture of hydrogen and carbon dioxide. Thus he definitely proved that hydrogen was one of the products of the nitrogen disintegration and one of the original compounds of the nitrogen nucleus.

Further evidence, he considered, indicated that there were atoms of mass 3 with two charges—a new isotope of helium. Thus nitrogen was disintegrated in collision with an alpha-particle in two independent ways, involving, as the case might be, the escape of a fast hydrogen or the new isotope. In the case of oxygen only the new isotope was released. Thus it was assumed that nitrogen and oxygen nuclei were compounds of these particles with or without hydrogen. That these particles possessed an energy 8 per cent greater than the original energy of the alpha-particle supported this view.

He also stated that the atoms consisted of 3 hydrogen nuclei with 1 binding electron similar to the helium (mass 4) scheme.

The definite proof of the existence of the swift-hydrogen particle was the first great step towards the eventual deliberate transmutation of matter.

But the mistaken deduction of the existence of particles of mass 3 was responsible for the amazingly accurate prophecy of the existence of the neutron and its properties, twelve years before its discovery. "It seems very likely that one electron can also bind two hydrogen nuclei and possibly also one hydrogen nucleus. In the one case this entails the possible existence of an atom of mass nearly two carrying one charge, which is to be regarded as an isotope of hydrogen.

In the other case it involves the idea of the possible existence of an atom of mass, one which has zero nuclear charge. Such an atomic structure seems by no means impossible. On present views, the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached to it at a distance and the spectrum of hydrogen ascribed to the movements of its orbital electron. Under some conditions, however, it may be possible for an electron to combine much more closely with the hydrogen nucleus, forming a neutral doublet. Such an atom would have very novel properties. Its external field would be practically zero, except very close to the nucleus, and in consequence it should be able to move more freely through matter. Its presence would probably be difficult to detect by the spectroscope, and it may be impossible to contain it in a thin vessel. On the other hand it should enter readily into the structure of atoms, and may either unite with the nucleus or be disintegrated by its intense field resulting possibly in the escape of a charged hydrogen atom or an electron or both.

'The existence of such an atom seems about necessary to explain the building up of nuclei of heavy elements; for unless we suppose the production of charged particles of very high velocities it is difficult to know how any positively charged particle can reach the nucleus of a heavy atom against its intense repulsive field.'

Besides the fulfilment of the neutron prophecy, that of hydrogen mass 2, now known as 'heavy hydrogen,' was also fulfilled.

Aston's positive ray apparatus he had used in his investigations concerning isotopes had now been developed by him into a precise measuring instrument. Aston was thus able to show that the atomic weight of each isotope was almost an exact integer. If this was to be definitely verified, then it was possible that all nuclei were constructed of hydrogen nuclei cemented together by electrons. For example, chlorine has two isotopes of 35 and 37; which have been isolated by a very long and tedious chemical method; in other words, chlorine consists of a mixture of two atoms in a proportion to give an average atomic weight of 35·46. The 35 isotope consists of 35 hydrogen nuclei, positively charged and cemented together with 18 electrons, while the

37 isotope consists of 37 hydrogen nuclei cemented together with 20 electrons.

In both cases we get a resultant positive charge of 17, which is the atomic number of chlorine.

There is one difficulty about the whole number of the nucleus, for the hydrogen nucleus is not 1 but 1·008.

Another fact is the tendency of the hydrogen electrons to form sub-groups of helium. The tendency can be explained by the application of Einstein's theory of relativity. By this theory energy means mass. From Aston's data the mass of the free hydrogen nuclei is 1·0072, and the mass of the helium nucleus 4·0011. If the helium nucleus is a combination of 4 hydrogen nuclei and 2 electrons, there is a loss in mass, which means a loss in energy. Thus, a large amount of energy is radiated in the formation of helium nucleus, giving one reason for its being so stable.

Further developments of Aston's mass spectrograph were given at the British Association meeting in August 1920, at Cardiff, when it was announced that it had been possible to demonstrate that boron had two isotopes ; neon, silicon, and chlorine, two or three ; bromine, two ; the rare gas krypton, six ; and mercury at least two.

At the same Cardiff meeting Rutherford solved the terminological trouble about the positive electron, or rather the positively charged hydrogen nucleus, by calling it the 'proton.'

By the end of 1920 the counting method had been improved considerably from the optical point of view, and it was definitely proved that the swift hydrogen atoms from nitrogen had a much greater range than those from hydrogen. For example, hydrogen atoms produced by an alpha-particle of 7 cm. range from hydrogen or a hydrogen compound have a maximum range corresponding to 29 cm. of air, while those from nitrogen have a range of 40 cm. of air, thus showing that in the latter case the hydrogen particles do not arise from any hydrogen contamination.

A new series of experiments were then carried out. The material under examination, either a gas or a thin film of oxide, was exposed to alpha-particle, and the observations taken at a range corresponding to 32 cm. of air, that is, out of the range of free hydrogen particles. In this way Ruther-

ford and Chadwick found that boron, fluorine, aluminium, and phosphorus were also definitely disintegrated. But they found no appreciable disintegration of the elements: lithium, beryllium, carbon, magnesium, silicon, sulphur, chlorine, potassium, calcium, titanium, manganese, iron, copper, tin, and gold.

The gases, carbon dioxide and sulphur dioxide, were examined for distances less than 32 cm. of air, but no trace of the swift hydrogen particles was found. Elements with ranges of less than 40 cm. were not examined at this time, but it was found that aluminium gave particles of the extraordinary range of at least 80 cm., or 25 per cent, greater energy than the incident alpha-particle.

The host of elements that refused to allow themselves to be disintegrated were found to be the so-called 'pure elements,' whose atomic masses are of the 4n type, where n is a whole number ; but disintegration was very marked in the $4n+2$ and $4n+3$ types. This result had been anticipated, since the atoms of the 4n type are built up of stable helium nuclei, and those of the $4n+1$, 2, or 3 types of helium and hydrogen nuclei. In any case it was found that no atom of mass greater than 31 gave any protons on collision with alpha-particles. Rutherford said that if this was to prove general, then alpha-particles of even greater velocity than those from radium-C would be required. The position also suggested that in the lighter elements the hydrogen nuclei were satellites of the main nucleus, while in the heavier atoms they formed part of the interior structure of the nucleus.

Useful as this speculation was, Rutherford and Chadwick were cautious when they said :

" Until accurate date are available as to the effect of velocity of the alpha-particle on the number, range, and distribution of the liberated particles, it does not seem profitable at this stage to discuss the possible mechanism of these atomic collisions which lead to the disintegration of the nucleus."

In the following April Rutherford discovered that his deduction regarding helium isotopes of mass 3 as products of certain disintegrations was unfounded. Using a powerful source of thorium-C, he found that the supposed

'short-range' particles of mass 3 were, in reality, alpha-particles after all. One of Rutherford's few errors in deduction.

At that time it was thought that intense heat might be capable of causing disintegration; but a note from Rutherford indicated that such a process was not possible with the means at our disposal on this planet: "It is reported that when a powerful condenser charge of 100,000 volts was sent through a very fine tungsten wire, the filament exploded with a 'deafening report,' producing a flash estimated to correspond to a temperature of 50,000° F. The telegram states that 'after the flash, Dr. Wendt found atoms of tungsten decomposed into simple atoms, and the result was the change of metallic tungsten into gaseous helium.'

"The experiments were made to investigate whether any atomic disintegration can be affected by high-temperature discharges, and apparently the authors believed that they had obtained positive results.

"We must await a much fuller account of the experiment before any definite judgment can be formed; but it may be of interest to direct attention to one or two general points. During the past ten years many experiments have been recorded in which small traces of helium have been liberated in vacuum tubes in intense electrical discharges, and it has been generally assumed that the helium has been in some way occluded in the bombarded material.

"On modern views, we should anticipate that the disintegration of a heavy atom into light atoms, for example, into atoms of helium, would be accompanied by a large evolution of energy. Indeed, it is to be anticipated that the additional heating effect due to this energy would be a much more definite and more delicate test of disintegration of heavy atoms into helium than the spectroscope.

"Our common experience of the large effect of temperature in ordinary chemical reaction tends to make us take a rather exaggerated view of the probable effects of high temperature on the stability of atoms.

"While it seems quite probable that momentary temperatures of 50,000° F. can be obtained under suitable conditions in condenser discharges, it should be borne in mind that the average energy of an electron in temporary equilibrium

WILSON CLOUD CHAMBER PHOTOGRAPHS

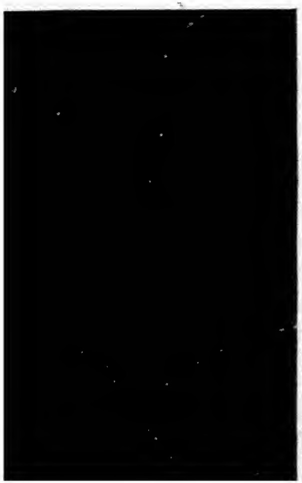


FIG. 1.

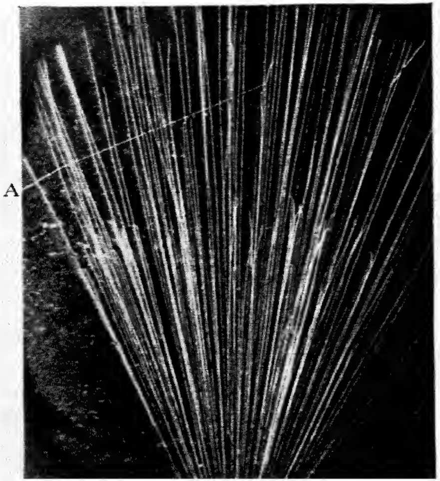


FIG. 2.

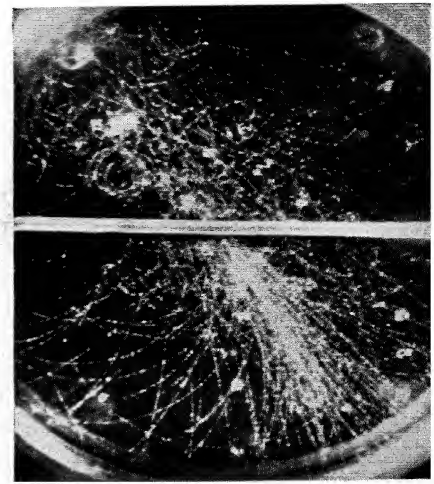


FIG. 3.

Fig. 1. Beta-rays or electrons ejected from air by X-rays.
Note their erratic paths showing how easily these light particles are scattered.

Fig. 2. The transmutation of a nitrogen atom by an alpha-particle. On following the path of the ejected proton from 'A' to where it meets an alpha-particle track a short spur will be seen—the transmuted nitrogen atom.
Note how little scattered are the other alpha-tracks.

Fig. 3. The beautiful effect of a cosmic ray shower of over 100 particles.

All reproduced by courtesy of the Director of the Science Museum, South Kensington, London, and Figs. 1 and 2 also by courtesy of the Royal Society, London.

with atoms at this temperature corresponds to a fall in potential of *only six volts.*[1]

"In many physical experiments we habitually employ streams of electrons of much higher energy, and yet no certain trace of disintegration has been noted. In particular, in the Coolidge Tube, an intense stream of electrons of *energy corresponding to* 100,000 *volts*[1] is constantly employed to bombard a tungsten target for long intervals, but *no evolution of helium has so far been observed.*"[1]

Rutherford's note above, which appeared in *Nature*, cleared up many of the misapprehensions that existed at the time.

We will pause for a moment to summarize the properties of the atom as known in 1921.

The Atom

1. Electrons occupy, rather than fill, a region about 2×10^{-8} cm. in diameter.
2. The position of the atom in the periodic table, that is, its atomic number, represents the number of orbital electrons.
3. By the action of light and electrical discharges we can readily remove one or more of the external planetary electrons from the atom, while, by the action of X-rays and swift beta-rays, we may even eject one of the more strongly bound electrons in the system. In this way a transformation of the atom can be effected, but only a temporary one, since a new electron is soon captured from the outside and the atom is as before.
4. Isotopes consist of atoms of the same nuclear charge, but of different nuclear masses.
5. Stability of the nucleus is disturbed by the removal of planetary electrons.
6. In order to effect a *permanent* change it is necessary to disrupt the nucleus itself. Once removed from the nucleus, the charge cannot be replaced.
7. The nuclei of heavy atoms contain both positive helium and negative electrons and lead to a general view that the complex nuclei of all atoms are built up of hydrogen and helium nuclei.

[1] Author's italics.

8. The helium nucleus is supposed to be composed of four hydrogen atoms and two electrons. If that be the case, it may be supposed that the nuclei of all atoms are composed ultimately of hydrogen nuclei or 'protons,' with the addition of the negative electron.

Rutherford determined the diameter of the nucleus as of the order of 4 million millionths cm., or about 1/5000th of the diameter of the whole structure of the atom.

One very vivid picture of the extent to which an atom can be disintegrated is given by the fact that if all the alpha-particles from one gramme of radium were fired into aluminium, only 1/1000th of a cubic millimetre of hydrogen would be liberated in one year.

"This is just a beginning," said Rutherford. "Many things remain to be known, and there are great numbers of unsolved problems."

Amongst those problems were the following :

What is left when hydrogen is expelled from the nucleus of an atom ?

Boron has two isotopes 10 and 11, that is, of the $4n+2$ and $4n+3$ type. Both should give hydrogen particles, but lithium, with isotopes of 6 and 7, ought to give hydrogen particles, but does not. Why ?

What is the critical energy needed by the alpha-particle to liberate hydrogen, that is, the least amount required ?

Aluminium gives particles of the immense range of 90 cm. of air. In addition, some of the particles from aluminium are shot backwards as well. The case of phosphorus is similar. Why ?

It also appears not improbable that the alpha-particle may occasionally be able to disrupt a helium atom from a complex nucleus like carbon or oxygen, which are believed to be composed of 3 and 4 helium nuclei respectively. Why ?

The fact that the masses of the above atoms are an integral multiple of the mass of the helium nucleus suggests that the helium nuclei are bound together with much weaker forces than the hydrogen compounds of the helium nucleus itself. Why ?

There is only a net loss of 0·008 units when four atoms of

helium, mass 4·002, unite to form one atom of oxygen mass 16·000. On the other hand, four atoms of hydrogen of mass 1·007 combining to form an atom of helium cause a net mass loss of 0·026, indicating that over three times the amount of energy is required to build a helium atom from hydrogen atoms than for an oxygen atom from helium atoms. Why?

These were problems that required many years of work.

Wilson's improved cloud chamber was now to be employed in a great series of investigations, instead of the laborious and trying scintillation method. In the hands of Blackett tens of thousands of photographs were to be taken of alpha-particles shot at the heavier elements, above element 31. These photographs were taken automatically and stereoscopically by a special camera. It was going to be a long and tedious work since results were only obtained from one in ten thousand photographs, but it was possible to show the existence of the short-range protons that, owing to technical difficulties, cannot be detected by the scintillation method.

And so another chapter was started.

CHAPTER XII

THE LIFE HISTORY OF AN ALPHA-PARTICLE

MORE honours poured on Rutherford. The University of Copenhagen made him a Doctor of Science of that University; he was appointed Fellow in the Physics and Mathematical classes of the Royal Danish Society of Science. He was awarded the Copley Medal of the Royal Society for his work on radio-activity, and he was nominated President of the British Association for the 1923 meeting.

Rutherford was now beginning the work for closer collaboration between science and industry, and investigating the humane benefits which could be derived from radium treatment. The seeds he then sowed have borne much fruit.

On 15 June 1923 he gave a lecture at the Royal Institution entitled, 'The Life History of an Alpha-particle,' which dealt with much of the work done during the first three years of his directorship of the Cavendish Laboratory.

He tentatively suggested that it was probable that the alpha-particle in escaping from radio-active nuclei acquired part of its energy of motion in passing through the repulsive electric fields surrounding the nucleus.

When the alpha-particle is shot out, it is curious that the shorter the half-period of a radio-active element, the swifter is the speed of the alpha-particle. This interesting relation between the violence of the explosion and the average life of the element holds good in the majority of cases, but, as Rutherford said, it is difficult to be at all clear as to its underlying meaning.

Meanwhile, G. H. Henderson, under Rutherford's direction, had investigated the capture and loss of electrons by alpha-particles and showed that swift alpha-particles

capture electrons and are thus converted into singly charged and neutral helium atoms.

Further, it was found that for any given velocity there is a temporary equilibrium between the number of singly and doubly charged particles, so that the number of electron captures is equal to the number of losses.

Measurements were made of the mean free path of the singly charged alpha-particle. In hydrogen the path was found to be five or six times longer than in air under the same conditions. In air the results were that an alpha-particle with a velocity of 1500 million cm. per second travels, on the average, just half a millimetre before it picks up an electron and becomes a singly charged alpha-particle. After travelling another tenth of a millimetre it loses that electron and becomes a doubly charged particle once more. Thus the mean free path of a singly charged alpha-particle is about one-tenth of a millimetre. Rutherford confirmed these results by the scintillation method.

Henderson then went on to find the conditions governing the gain and loss of electrons by the flying alpha-particle. He first of all found that at 3·5 cm. from the source only 1/55 of the helium particles were singly charged. At 6 cm. absorption the ratio of the singly charged helium particles to the doubly charged was 1:8, the ratio increasing as the velocity decreased until they finally merged.

" We may suppose," said Rutherford, " that the alpha-particle in passing through the outer electron structure of the atoms in its path occasionally removes and captures an electron. This electron falls into a stable orbit round the doubly charged helium nucleus and moves with it.

" This singly charged atom will, however, have only a limited life, for in passing through other atoms the electron is knocked off and the singly charged particle reverts back to the doubly charged type.

" This process of removal is analogous to the ordinary process of ionization, where an electron is ejected from an atom by a collision with an alpha-particle. . . . We may thus consider that two opposing forces are at work, one resulting in the capture of an electron and the other leading to its removal. . . . This process of capture and loss may repeat itself a thousand times in the flight of an alpha-particle . . .

it is rather astonishing when considering that an alpha-particle moves with a velocity of the order of 9,000,000 cm. per second to realize that it picks up and loses electrons at least 100 times in traversing a centimetre. If its flight lasted a whole second it would have picked up and lost electrons some thousand million times in that period.

"It is clear from this, for a given velocity of an alpha-particle, that there must be a momentary equilibrium between the number of singly and doubly charged helium particles, such that, on the average the number of captures over a given small distance is equal to the number of losses."

Similarly there is an equilibrium between the singly charged particles and the neutral helium atom.

"We can hardly suppose," said Rutherford, "that singly as well as doubly charged particles are actually liberated from the radio-active nucleus itself, for even if it is to be supposed that an alpha-particle with an attendant electron is expelled, the electron must be removed in escaping through the very powerful electric field close to the nucleus. It is much more probable that the doubly charged alpha-particle in passing through the dense distribution of electrons surrounding the radio-active mass occasionally captures an electron, and that the process of capture and loss goes on to the same extent in escaping from the radio-active atom. This seems at first unlikely when we consider the relatively large number of atoms an alpha-particle ordinarily passes through before equilibrium between capture and loss is established; but it is well known that the chance of effective electric collisions appears in general to be greater for a charged particle expelled from the central nucleus than for a similar particle passing through the electronic distribution of the atom. It may be that these electrons, the orbital motion of which round the nucleus is comparable with the speed of the alpha-particle, are particularly effective in causing capture and loss."

The result of this work of Rutherford and Henderson established agreement between their experimental and theoretical results.

In photographs of alpha-ray emissions from radio-active substance we can see that not all the particles have

the same range. For example, a substance giving alpha-particles of 7·0 cm. range has some particles of only 6·4 cm. range, resulting in an average range of 6·8 cm. This Rutherford termed 'straggling.'

Henderson suggested that the effect was due to the capture and loss of electrons. "But," said Rutherford, "the ratio of capture and loss is too great to account entirely for the discrepancy between the theoretical and practical results."

Chadwick and Bieler, at the Cavendish, gave an explanation which, based on the collisions between alpha-particles and helium, supposed that the alpha-particle or helium nucleus has an asymmetric field of force around it like a halo. The difference in chances of a helium nucleus being expelled from a radio-active element depended on the plane of this halo to the direction of the path of the alpha-particle when expelled.

Kapitza, at the Cavendish, photographed the tracks of a number of alpha-particles in very strong magnetic fields and obtained a marked bend in the tracks. He found that the curvature of the tracks at equal distances from the ends showed marked variations. An important trifle to be used later.

The results of Blackett's two years of photographing, in the Wilson Cloud Chamber, alpha-particle tracks, and examining the frequency of the occurrence of the sharp bends or forks near the end of their ranges in air and other gases, were now to hand.

Each track was photographed in two directions at right angles, thus getting the angles of the forks in space. Patiently he took photograph after photograph, concentrating his attention to the last centimetre of the range. He was thus able to calculate the variations in the velocity of the alpha-particle at the end of its range.

These photographs demonstrated that in collisions between an alpha-particle and other atoms the atoms behaved as perfectly elastic spheres, and it was thus possible to deduce the mass of the second atom in terms of the alpha-particle of mass 4. For example, in helium gas the mass of the recoil atom (helium atom) is 4·03, and in hydrogen the mass of the recoil atom (hydrogen) is 1·024.

Another example of the success of the experiment was the measurement of the angle between the forks for a collision between an alpha-particle and a helium atom. Since the two atoms are of the same mass, the angle should, by theory, be exactly a right angle or 90°. The experimental value gave 89° 45′.

Another important problem was the ionizing potential of the atom.

The maximum velocity of an alpha-particle from, for example, radium-C is equivalent to an electron falling freely between differences of potential of 1000 volts, so that the electron comprising the molecule of air or other gas has a velocity of translation in equivalent terms. For brevity's sake it is convenient to speak of this velocity or energy as that due to a ' 1000 volt ' electron.

Now, the energy required to ionize an atom of helium is 54 volts. In the case of oxygen only 17 of the 1000 volts of the alpha-particle are required. Thus, when an alpha-particle ionizes an oxygen atom it loses 17 volts by capturing an electron, so that when a singly charged helium atom changes back to an alpha-particle there is a gain of 17 volts. But there are other forces which have to be overcome. To get an electron away from oxygen required an energy of 500 volts. In the case of hydrogen 120 volts are needed ; but the binding energy in hydrogen is only 30 volts, so what becomes of the other 90 volts ?

Rutherford concluded that unknown factors were present, due to energy of radiation. He suggested that the radiation of the capture of an electron could be regarded as the converse of the photo-electric effect, where radiation falls on matter and swift electrons are ejected from the matter. However, information was still too incomplete to allow a definite answer to be given, and the loss of electrons was giving rise to new and interesting problems.

Leaving these further problems for the moment, let us end this chapter in Rutherford's own words.

" We have seen," he said, " that an alpha-particle has an interesting history. Usually it is retained as an integral and orderly part of the radio-active nucleus for an interval of more than 1,000,000,000 years. Then follows a cataclysm in the radio-active nucleus ; the alpha-particle gains its

freedom and lives an independent life of about one thousand millionth of a second, during which all the incidents referred to . . . occur.

"If we are dealing with a dense and compact uranium or thorium mineral, the alpha-particles after acquiring two electrons and becoming a neutral helium atom may be imprisoned in the mineral as long as the mineral exists. The occluded helium can be released from the mineral by the action of high temperature. . . . In the circumstances of such an experiment only small quantities of helium are liberated. Large quantities of helium sufficient to fill a large airship have, however, been isolated from natural gases which escape so freely from the earth in various parts of Canada and the United States.[1] It is a striking fact that every single atom of this material has in all probability had the life history here described."

And 1,000,000,000 atoms will just span a pennypiece!

[1] There are deposits of helium in Texas which are estimated to total 2,000,000,000 cubic feet.

CHAPTER XIII

PRESIDENT OF THE BRITISH ASSOCIATION

ON 12 September 1923 Rutherford delivered his presidential address to the British Association meeting at Liverpool. The address gave him an opportunity for expressing his views on various aspects of human activities, particularly that of the co-operation between industry and scientific research. It contained many succinct suggestions.

This meeting was the first occasion on which a physicist had occupied the presidential chair at a British Association meeting at Liverpool, and it was a happy coincidence that Rutherford was in it, since the Association met in a city intimately connected with all parts of the British Empire, himself being a conspicuous example of the part played by science as a bond of the communities of British people. It was a typical example of the opportunities offered to her sons by the British Empire and the unity of British science.

In 1923 broadcasting was in its infancy ; it was the day of the crystal set and headphones ; and Rutherford, a sometime pioneer of wireless research, was the first president of the British Association to broadcast his address.

He began :

" It was in 1896 that this Association last met in Liverpool under the presidency of the late Lord Lister, that great pioneer of antiseptic surgery, whose memory is held in affectionate remembrance by all nations. . . .

" In his opening remarks, Lister emphasized the importance of the discovery by Röntgen of a new type of radiation, the X-rays, which we now see marked the beginning of a new and fruitful era in another branch of science.

" The visit to your city in 1896 was for me a memorable occasion, for it was here that I first attended a meeting of this Association, and here that I read my first scientific paper.

But of much more importance it was here that I benefited by the opportunity which these gatherings so amply afford, of meeting for the first time many of the distinguished scientific men of Great Britain and the foreign representatives of science who were the guests of this city on that occasion.

"The year 1896," Rutherford went on, "has always seemed to me to be memorable for other reasons, for on looking back we cannot fail to recognize that the last Liverpool meeting marked the beginning of what has been aptly termed the heroic age of physical science. Never before in the history of physics has there been witnessed such a period of intense activity, when discoveries of fundamental importance have followed one another with such bewildering rapidity.

"In applied physics, too, this year (1896) marked the beginning of another advance. In the discussion of a paper which I had the honour to read, the late Sir William Preece told the meeting of the successful transmission of signals for a few hundred yards by electric waves which had been made in England by a young Italian, G. Marconi. The first public demonstration of signalling for short distances by electric waves had been given by Sir Oliver Lodge at the Oxford meeting of this Association in 1894. It is startling to recall the rapidity of the development from such small beginnings of the new method of wireless intercommunication over the greatest terrestrial distances. In the last few years this has been followed by the even more rapid growth of the allied subjects of radio-telephony as a practical means of broadcasting speech and music. . . . The rapidity of these technical advances is an illustration of the close inter-connection that must exist between pure and applied science if rapid and sure progress is to be made. The electrical engineer has been able to base his technical developments on the solid foundation of Maxwell's electromagnetic theory and its complete verification by the researches of Hertz and also by the experiments of Sir Oliver Lodge in the University of Liverpool—a verification completed long before the practical possibilities of this new method of signalling had been generally recognized. The later advances in radio-telegraphy and radio-telephony have

largely depended on the application of the results of fundamental researches on the properties of electrons, as illustrated by the use of the thermionic valve or electron tube. . . . It is of great interest to note that the benefits of this union of pure and applied research have not been one-sided.

"If the fundamental researches of the workers in pure science supply the foundations on which the applications are surely built, the successful practical application in turn quickens and extends the interest of the investigator in the fundamental problem, while the development of new methods and appliances required for technical purposes often provides the investigator with the means of attacking still more difficult questions.

"This important reaction between pure and applied science can be illustrated in many branches of knowledge. It is practically manifest in the industrial development of X-ray radiography for therapeutic and industrial purposes where the development on a large scale of special X-ray tubes . . . have given the physicist much more efficient tools to carry out his researches on the nature of the rays themselves and in the structure of the atom. In this age no one can draw any sharp line of distinction between the importance of so-called pure and applied research. Both are equally essential to progress, and we cannot but recognize that without flourishing schools of research on fundamental matters in our Universities and scientific institutions technical research must tend to wither. Fortunately there is little need to labour this point, for the importance of a training in pure research has been generally recognized. The Department of Industrial and Scientific Research has made a generous provision of grants to train qualified young men of promise in research methods in our scientific institutions, and has aided special fundamental researches which are clearly beyond the capacity of a laboratory to finance from its own funds. Those who have the responsibility of administering the grants in aid of researches in both pure and applied science will need all their wisdom and experience to make wise allocation of funds to obtain the maximum of results for a minimum of expenditure. It is fatally easy to spend much money in a direct frontal attack of some technical problem of importance when the solution may

depend on some addition to knowledge which can be gained in some other field of scientific inquiry at a trifling cost. It is not in any sense my purpose to criticize those bodies which administer funds for fostering pure and applied research, but to emphasize how difficult it is to strike the correct balance between expenditure on pure and applied science in order to achieve the best results in the long run."

After dealing with the matters which we have so far covered Rutherford said, with his usual farsightedness:

"While the progress of our knowledge of the outer structure electrons has been much more rapid than could have been anticipated, we clearly see that only a beginning has been made on this great problem, and that an enormous amount of work is still required before we can hope to form anything like a complete picture even of the outer structure of the atom. We may be confident that the main features of the structure are clear, but in a problem of such great complexity progress in detail must of necessity be difficult and slow.

"In a discussion on the structure of the atom ten years ago and in answer to a question on the structure of the nucleus I was rash enough to say that it was a problem that might well be left to the rising generation, for at that time there seemed to be few obvious methods of attack to throw light on its constitution. While much more progress has been made than appeared possible at that time, the problem of the structure of the nucleus is inherently more difficult than the allied problem already considered of the structure of the outer atom. . . ."

Later he discussed the energy of radio-activity.

"Since it is believed that the radio-active elements were analogous in structure to the ordinary inactive elements, the idea naturally arose that the atoms of all the elements contained a similar concentration of energy, which would be available for use if some simple method could be discovered of promoting and controlling their disintegration. This possibility of obtaining new and cheap sources of energy for practical purposes was naturally an alluring prospect to the lay and scientific man alike. It is quite true that if we were able to hasten the radio-active process in uranium and thorium, so that the whole cycle of their

disintegration could be confined to a few days instead of being spread over thousands of millions of years, these elements would provide very convenient sources of energy on a sufficient scale to be of considerable practical importance. Unfortunately, although many experiments have been tried, there is no evidence that the rate of disintegration of these elements can be altered in the slightest degree by the most powerful laboratory agencies. With increase in our knowledge of atomic structure, there has been a gradual change of our point of view on this important subject, and there is by no means the same certainty to-day as a decade ago that the atoms of an element contain hidden stores of energy.

"It may be that the elements, uranium and thorium, represent the sole survivals in the earth to-day of the types of elements that were common in the long distant ages, when the atoms now comprising the earth were in course of formation. A fraction of the atoms of uranium and thorium formed at that time has survived over the long interval on account of their very low rate of transformation. It is thus possible to regard these atoms as having not yet completed the cycle of changes which the ordinary atoms have long since passed through, and that the atoms are still in the 'excited' state where the nuclear units have not yet arranged themselves in positions of ultimate equilibrium, but still have a surplus of energy which can only be released in the form of the characteristic radiation from active matter. On such a view the presence of a store of energy ready for release is not a property of all atoms, but only of a special class of atoms like the radio-active atoms which have not yet reached the final state for equilibrium.

"It may be argued that the artificial disintegration of certain elements by bombardment with swift alpha-particles gives definite evidence of a store of energy in some of the ordinary elements. . . . Unfortunately, it is very difficult to give a definite answer on this point until we know more of the details of this disintegration."

He then went on to discuss the mass-energy relationships between helium nuclei and protons. He said that the energy of formation of one pound of helium from four protons is equivalent to the combustion of about 8000 tons

of pure anthracite coal, while Eddington had suggested that the heat of the very hot stars is due to protons forming helium. Another illustration of this tremendous energy was that the sun's loss of heat showed that the synthesis of helium need only take place there slowly to maintain the present rate of radiation for one thousand million years. Lastly, he said that at the moment there was no experimental evidence of the formation of helium from hydrogen, but both the elements were much in evidence in the very hot stars.

"While electric discharge through hydrogen at low pressure can easily reproduce the conditions of the interior of the hottest star so far as regards energy of motion of the electron and hydrogen nucleus, we cannot hope to reproduce that enormous density of radiation which must exist in the interior of a giant star. For this and other reasons it may be very difficult or even impossible to produce helium from hydrogen under laboratory conditions.

"In these great additions to our knowledge of the structure of matter every civilized nation has taken an active part, but we may be justly proud that Great Britain has made many fundamental contributions. With this country I must properly include the Dominions overseas. . . . It is, I am sure, a matter of pride to this country that the scientific men of the Dominions have been responsible for some of the most fundamental discoveries of this epoch, particularly in radio-activity.

"This tide of advance was continuous from 1896, but there was the inevitable slackening during the war. It is a matter of good omen that, in the last few years, the old rate of progress has not only been maintained but even intensified, and there appears to be no obvious sign that this period of great advances has come to an end.

"There has never been a time when the enthusiasm of scientific workers was greater, or when there was a more hopeful feeling that great advances were imminent. . . . In the main, the epoch under consideration has been an age of experiment, where the experimenter has been the pioneer in the attack on new problems. At the same time, it has been also the age of bold ideas in theory, as the quantum theory and the theory of relativity so well illustrate."

We know how much of the work thus described was due to the pioneering of Rutherford. The last part of his address again illustrates that simplicity was the keynote of his genius.

Although Rutherford had no reason to challenge the correctness of Tennyson's 'The old order changeth, yielding place to new,' he did not forget the honour due to those of the old order, for it was they who laid the foundations on which he had built so well.

He said: "I feel that it is a great privilege to have witnessed this period, which may almost be termed the Renaissance period of physics. It has been of extraordinary intellectual interest to watch the gradual unfolding of new ideas and the ever changing methods of attack on difficult problems. It has been of great interest, too, to note the comparative simplicity of the ideas that have ultimately emerged. For example, no one could have anticipated that the general relation between the elements would prove to be of so simple a character as we now believe it to be. It is an illustration of the fact that Nature appears to work in a simple way, and that the more fundamental the problem, often simpler are the conceptions needed for its explanation. . . .

"In watching the rapidity of this tide of advance in physics I have become more and more impressed by the power of the scientific method of extending our knowledge of Nature. Experiment, directed by the disciplined imagination either of an individual, or, still better, of a group of individuals of varied mental outlook, is able to achieve results which far transcend the imagination alone of the greatest natural philosopher. Experiment without imagination, or imagination without recourse to experiment, can accomplish little, but, for effective progress, a happy blend of these two powers is necessary. The unknown appears as a dense mist before the eyes of men. In penetrating this obscurity we cannot invoke the aid of supermen, but must depend on the combined efforts of a number of adequately trained ordinary men of scientific imagination. Each in his own special field of inquiry is enabled by the scientific method to penetrate a short distance, and his work reacts upon and influences the whole body of the other workers.

From time to time there arises an illuminating conception based on accumulated knowledge, which lights up a large region and shows the connection between these individual efforts, so that a general advance follows. The attack begins anew on a wider front, and often with improved technical weapons. The conception which led to this advance often appears simple and obvious when once it has been put forward. This is a common experience, and the scientific man often feels a sense of disappointment that he himself had not foreseen the development which ultimately seems so clear and inevitable.

"The intellectual interest due to the rapid growth of science to-day cannot fail to act as a stimulus to young men to join in scientific investigations. In every branch of science there are numerous problems of fundamental interest and importance which await solution. We may confidently predict an accelerated rate of progress of scientific discovery, beneficial to mankind certainly in a material but possibly even more so in an intellectual sense. In order to obtain the best results certain conditions must, however, be fulfilled. It is necessary that our Universities and other specific institutions should be liberally supported so as not only to be in a position to train adequately young investigators of promise, but also to serve themselves as active centres of research. At the same time there must be a reasonable competence for those who have shown a capacity for original investigation. Not least, peace throughout the civilized world is as important for rapid scientific development as for general commercial prosperity. Indeed, science is truly international, and for progress in many directions the co-operation of nations is as essential as the co-operation of individuals. Science, no less than industry, desires a stability not yet achieved in world conditions."

In these days of international unrest, when the politician never ceases to trouble, and there is no quiet for mankind in general any more, Rutherford's words hold out a little hope. They are essentially true, and it may be yet that through the mediumship of the scientist international co-operation will take the place of jealousy and mistrust. It may be that only in the quiet of the laboratory, where research workers come face to face with Nature as nowhere

else, will men be able to segregate themselves from the plague afflicting the world, there only to preserve their sanity. Let us fervently hope that Rutherford's words soon come true.

He then went on to say : " There is an error, too prevalent to-day, that science progresses by the demolition of former well-established theories. Such is rarely the case ; for example, it is often stated that Einstein's general theory of relativity has overthrown the work of Newton on gravitation. No statement could be further from the truth. Their works are, in fact, scarcely comparable, for they deal with two different fields of thought. So far as the work of Einstein is relevant to that of Newton it is simply a generalization and a broadening of its basis ; in fact, a typical case of mathematical and physical development. In general, a great principle is not discarded, but is so modified that it rests on a broader and more stable basis."

Rutherford ended his address with a magnificent tribute to the past.

" It is clear that the splendid period of scientific activity which we have reviewed to-night owes much of its success and intellectual appeal to the labours of those great men in the past who wisely laid the sure foundations on which the scientific worker builds to-day, or, to quote from the words inscribed in the dome of the National Gallery : 'The works of those who have stood the test of ages have a claim to that respect and veneration to which no modern can pretend.' "

In his own day Rutherford earned a respect and veneration almost unparalleled in the history of science. How much greater will be the respect and veneration which future generations will have for this colossus amongst men ?

Rutherford was very enthusiastic about the success of this meeting of the British Association and about the broadcast of his speech by wireless. On moving the vote of thanks on the closing of the session a few days later he said that the meeting had been the largest of the five meetings held in Liverpool. As regards numbers attending, it was the third largest meeting in the history of the Association.

When he referred to the broadcasting of his address, Rutherford humorously said that he had been murdered to make a Roman holiday, but he added that he had received

many personal letters not only from friends, but from young people he did not know in many parts of Britain, saying that they had heard the address quite clearly and had enjoyed it. One message came from Switzerland saying that the writer picked up the speech quite clearly at that (then) great distance.

The effective manner in which Rutherford delivered his address made an indelible impression on many minds. When the author was speaking of the death of Rutherford to a sturdy and active little lady of eighty-three, who, in the ordinary way, takes no notice of things scientific, she instantly broke in :

" Oh, yes. He was the man who talked about the atom on the wireless fourteen years ago ! "

Rutherford would have been as pleased with that as with any of the great compliments ever paid him.

CHAPTER XIV

BUILDING FOR THE FUTURE

IN comparison with Rutherford's previous periods, that between 1919 and 1932 seemed to be almost unproductive calm. The general public likes sensational discoveries, and it is only at times when it can be given reports of such things as the discovery of the nuclear atom and artificial disintegration that it takes any interest in what is going on behind the scenes in the laboratory, or, for that matter, realizes that such men as scientists exist.

But science requires periods during which it can quietly investigate new facts and clear up the debris caused by upheavals and the revision of old theories.

The space was particularly welcomed by Rutherford, who organized the Cavendish for the wholesale investigation of the numerous fundamental problems now requiring as rapid a solution as possible.

Rutherford was now one of the most prominent workers in the scientific world. As a sign of his position he began to be known to the general public, being in demand as a public speaker and an interpreter of modern science. He was elected President of the Royal Society, the highest honour a scientist can receive from brother scientists. Honours from numerous other quarters were showered on him, including the Order of Merit in 1925.

In the laboratory the investigation of the disintegration of the alpha-particle was continued with keen interest and with worthy results. Rutherford and Chadwick continued their brilliant partnership.

Up to that date the protons ejected in an alpha-particle bombardment could only be examined by the scintillation method at ranges greater than that of the free proton—30 cm. of air. However, Rutherford and Chadwick devised

a method by which they could be examined within this range.

Making use of the fact that the ejected proton of an artificial disintegration shoots off in any direction they placed the zinc sulphide screen in a position to detect those coming off at right angles to the path of the incident alpha-particle, thus cutting out any stray alpha-particles.

By this method they were able to detect particles of a range of over 7 cm. with certainty, for it was found, on bombarding paraffin wax, that the presence of hydrogen in the bombarded material had no effect on the screen.

They found that neon, magnesium, silicon, chlorine, argon, and potassium could be disintegrated to give particles of ranges varying between 16 and 30 cm. of air.

One unusual fact came to light. Sulphur, a 'pure' element (nucleus 4n), disintegrated, liberating much energy. It was concluded that the sulphur nucleus was not composed wholly of helium nuclei, a conclusion suggested by its atomic weight of 32·07.

No disintegration effects were observed for nickel, copper, zinc, krypton, paladium, silver, tin, xenon, gold, or uranium.

Rutherford said at the time: "We hope to make a systematic examination of the elements with an improved counting microscope in order to settle definitely whether any evidence of disintegration can be obtained. In the case of the lighter elements it should be possible to carry the exploration for particles and disintegration down to about 3 cm."

Continuing their investigations, Rutherford and Chadwick found that the particles of 9·3 cm. and 11·2 cm. range appeared in equal amounts in vacuum whatever element was bombarded and whatever kind of absorbing screen was used, and they came to the conclusion that these particles arose from the disintegration of radium-C. These two groups were thought to be due to new types of disintegration within the atom of radium-C, suggesting complications in natural radio-activity.

The problem of the atomic constitution had now divided itself naturally into two great divisions—the arrangements and motion of the outer electrons on which depended the

optical and X-ray spectra of the element, and the structure of the minute nucleus at the heart of the atom.

The first problem Rutherford left to others while he investigated that minute world of its own which was held together by powerful forces and was little, if at all, influenced by ordinary chemical reagents—the nucleus.

By studying the variation of the number of alpha-particles of different initial velocity scattered backwards during a bombardment, it was found that there was a sudden change in the law of scattering for aluminium. Again, experiments with thin films of gold and uranium showed that the inverse square law held to a distance of 3 billionths of a cm., the closest approach of an alpha-particle to the nucleus. This was remarkable, because it had been supposed that the sphere of influence of the uranium nucleus extended to more than twice this distance. It was suggested by way of explanation of this effect that there might be satellites of electric doublets (positive and negative charges together) round the nucleus.

Then Blackett discovered the fate of the alpha-particle after a disintegrating collision. In the case of nitrogen it was captured, by the nucleus. Thus, the disintegration of nitrogen was really a building up. However, Rutherford accepted this result reservedly until the arrival of corroborative evidence.

From the results of further experiments Rutherford and Chadwick found that the ordinary laws of collision could be applied to the artificial disintegrations and they were able to calculate the distribution of momentum among the participating particles.

They found that the velocity of the escaping proton was small in the case of collisions with nitrogen, sodium, aluminium, and phosphorus, but considerable in the case of boron and fluorine.

In the case of the bombarding alpha-particle, they found that the greater its velocity the greater were the number of collisions leading to the expulsion of a proton and that particles with a range less than 5 cm. failed to disintegrate aluminium.

Much of this work was studied from photographs in a cloud chamber, and since, on the average, only one alpha-

particle in 40,000 liberates a proton when the swiftest rays are used, Blackett had to photograph the tracks of some 400,000 alpha-particles in order to obtain visible confirmation of a single reaction.

In addition to a number of collisions of the alpha-particle with the nitrogen nucleus, which obeyed the ordinary laws, Blackett observed eight forks on the alpha-ray tracks where the laws were not obeyed. The fine track of the proton was clearly visible, but there was no sign of a third track of an escaping alpha-particle. He concluded that it had been captured by the nitrogen nucleus and that the recoil atom now had a mass 17 and charge 8—an isotype of oxygen. This clear and decisive disclosure of the path of the alpha-particle in a nuclear disintegration reaction definitely established its mechanism. Other data were observed to be in accord with theoretical assumptions.

Rutherford said :

" In view of the evidence obtained by Blackett of the capture of an alpha-particle, I have thought it of interest to bring attention to two clear statements of the likelihood of such a capture in a collision which leads to the expulsion of a proton. In a discussion of a paper on the structure of the atom, read by me before the Solvay International Institute of Physics in 1921, a reference to this question was made by Professor J. Perrin. He said :

" ' Les expériences mêmes de M. Rutherford semblent prouver qu'il faut renoncer à cette idée d'un simple choc. Le projectile alpha en raison de sa grande vitesse, et malgré une très forte repulsion électrique, peut arriver, très ralente, au voisinage immédiat du noyau. A ce moment, une " transmutation " se produit, consistant probablement en un réarrangement intranucléaire, avec capture possible du rayon alpha incident (car nous ne savons pas ce qu'il devient), émission du rayon d'hydrogen format le rayon H observe, et peut-être encore avec d'autres projections moins importantes. Il n'y a aucune raison dans cette façon de voir, pour que le projectile H ému se souvienne de la direction du choc initial ni pour que son énergie (enpruntée pour une parte a l'énergie électrique intranucléaire) soit inférieure à celle du projectile incident.

" ' Si par example, le noyau d'aluminium heurté capture

le projectile alpha et n'émet pas d'électrons, il reste, après l'émission du projectile H, un atom dont la masse est 27+4−1, soit 30, et dont le numéro d'ordre est 13+2−1, soit 14, donc un atome isotope du silicium. D'autres hypothèses seraient d'ailleurs faciles.' "

Rutherford continued : " It seems clear, however, that a large amount of careful quantitative work as well as a great number of photographs of alpha-ray tracks will be required before we can hope to obtain detailed evidence of the mechanism of such collisions and of the fate of the bombarding alpha-particle for all ' active ' elements."

In November 1925 Rutherford and Chadwick announced that they had found that the inverse square law held for the heavy elements ; but in the case of magnesium and aluminium the number scattered in an observed direction for alpha-particles above 5 cm. range was considerably less than for other elements. They considered that these facts pointed to the central nuclei in the aluminium and magnesium atoms being surrounded by a shell of negative charges beyond which was a further wall of negative charges. The alpha-particles could penetrate the outer shell, but were repelled by the field caused by the difference between the nuclear positive and the inner wall of negative charges. They were thus less scattered than those which did not approach the centre of an atom so closely. There was a critical surface or a potential maximum, where the nuclear and outside fields met.

" In the year 1911," said Rutherford during the Guthrie Lecture for 1927, " when I put forward the nuclear theory of atomic structure based on the interpretation of the simple scattering of alpha-particles by matter, there seemed little hope of any immediate progress in our knowledge of the detailed construction of the nucleus. So much so was this the case that in a discussion on atomic structure before the Royal Society in 1913 in answer to an inquiry as to the constitution of the nucleus, I replied that a consideration of this question has but been left to the next generation. While more progress has been made in the interval than seemed likely at that time, we cannot but recognize that only a beginning has yet been made in the attack on this difficult and fundamental problem in physics."

He then described the suggestion he had put forward in 1924 depicting the central nucleus as a close, ordered arrangement of alpha-particles and electrons in a semi-crystalline formation. He was still inclined to believe, he said, that the central nucleus of the heavier elements was a very compact structure, occupying a small volume of radius about 1 billionth of a cm. The neutral satellites circulating around this nucleus, however, might extend to a distance which was large compared with the lineal dimensions of the main nucleus. There was, therefore, a fairly safe basis on which to build the modern conception of the atom, and it may be noticed that although the neutron had not yet been discovered, Rutherford placed reliance on its existence.

As the months went by Rutherford and Chadwick obtained further results. They found that the critical surface where the outside field met that of the nucleus was only 3·2 billionths of a cm., from the centre of the uranium nucleus.

Since the alpha-particle must gain its energy in escaping the repulsive field, Rutherford was able to calculate results that gave him some idea from what part of the nucleus the particle originated. In an atom of mass 90 it was from a point not less than 7 billionths of a cm. from the centre of the nucleus.

From all the data at his disposal Rutherford concluded that the magnetic and electric fields around the nucleus caused the alpha-particle to exist as a special type of neutral helium atom circulating round the nucleus.

The extra-nuclear electrons of the helium atom circulated in orbits dictated by the intense fields, otherwise they would be torn off. When the fields fell below a certain value the orbits ceased to exist and the neutral helium atom would, on its escape from the nuclear structure, be robbed of electrons on reaching the critical surface and issue as free alpha-particles. The theory agreed with facts.

Rutherford therefore concluded that a picture might be given of the mechanism of the emission of an alpha-particle by a radio-active element.

Occasionally one of the neutral alpha-particles circulating in quantized orbits is for some cause displaced from its position of equilibrium and has sufficient energy of motion to escape from the attractive field of the central nucleus. When

this field falls below the initial value, the neutralizing electrons are removed and fall backwards towards the nucleus. The alpha-particle now having two positive charges gains additional energy in passing through the repulsive electrical field of the nucleus and emerges as a high-speed alpha-particle. Thus all the alpha-particles which escape from radio-active nuclei have their origin as neutral satellites.

The electrons liberated from the alpha-particle must fall back towards the main nucleus, where they probably describe orbits under the complicated system of forces that exist close to the nucleus. Occasionally one of these electrons is given sufficient energy to escape entirely from the nucleus, thus giving rise to a beta-particle transformation.

In the nucleus itself is an inner nucleus carrying a positive charge and surrounded at a short distance by a number of electrons, while at a greater distance a number of neutral satellites circulate round the system.

The same applies to ordinary atoms. The neutral satellites were of mass 4, but Rutherford considered that it was quite possible that neutral masses of 2 and 3 were present. Still predicting the neutron, he said that it was possible that it never existed in the free state.

This view offered a reasonable explanation of the existence of a number of isotopes of a given element. When once the central nucleus is formed, a number of neutral satellites can be added, which are kept in equilibrium by attracting forces. Aston had shown that in some cases a large number of isotopes of one particular element could exist, thus indicating that a number of satellites could be added without disturbing the equilibrium of the nuclear system. He had also drawn attention to the fact that in all cases the odd-numbered heavy elements have either no isotopes or two isotopes differing in mass by 2 units, while even-numbered elements might have a whole group of them.

This striking distinction between elements is paralleled by the observation that odd-numbered elements which are disintegrated by bombardment of the alpha-particle emit protons at a much higher average speed than the even-numbered elements which are much more abundant in Nature than the odd-numbered.

Rutherford interpreting these facts said : " It is supposed

that the central nucleus is ordinarily made up of helium nuclei carrying two positive charges arranged in an ordered way, and for an even-numbered element there must be present an even number of electrons."

He said the system would arrange itself so that all the forces were at their lowest equilibrium level. If a proton or an electron is added or removed an odd-number is formed and the equilibrium upset. Thus the behaviour of the magnetic forces in an odd element might, Rutherford assumed, differ markedly from those of the even numbered.

Concerning the significance of the neutral satellite he said: "If the presence of neutral satellites in the nuclear system depends mainly on the electric charge of the nucleus the addition of such satellites may be possible only when the nuclear charge exceeds a certain value. For this reason the constitution of the lighter elements may differ markedly in general features from the heavier elements and the departures from the whole number rule of atomic mass may be more emphasized than for the heavier elements."

Meanwhile Aston was determining accurately the atomic masses of the lighter elements. From these results Rutherford hoped to obtain valuable information on the closeness of the binding of the component protons and electrons.

His views in 1927 were considered to be speculative in character, and the suggestion that magnetic fields played a part in the structure of the atom was considered novel. But the year was definitely the start of a series of very important revelations of the processes going on in the heart of the atom.

Rutherford's first Presidential Address to the Royal Society was concerned mainly with high voltages and magnetic fields. He drew attention to the fact that very much more powerful magnetic fields and higher voltages were required in order to push on investigations into the atom.

In 1927 weak currents at 200,000 to 300,000 volts were easily produced by electro-static machines and induction coils. The use of X-rays for hospital purposes had grown immensely and thus had been developed methods for producing very penetrating X-rays for deep therapy. This had necessitated light transformers supplying small currents at voltages from 300,000 to 500,000 volts.

Rutherford mentioned the Tesla transformer, which transformed the discharges from a Leyden jar up to voltages of 1,000,000, while the Carnegie Institute had actually obtained 5,000,000 volts. The secondary current of the Tesla transformer was so slight and rapidly oscillating that there was an immunity from long sparks, and it could be taken through the body without harm. This small energy restricted the use of the transformer.

The most effective method was to arrange transformers in series, which provided powerful high voltages giving sparks several yards long. Much as these sparks resembled lightning they did not by any means approach the thousand million volt potential provided by Nature.

The only limit to the voltage obtainable was cost and the size of the building required to install the cascade of transformers. The wealthy American General Electric Co. of Schenectady had a working plant in 1927 giving 2,800,000 volts, and was constructing another to give 6,000,000 volts.

Said Rutherford : " While no doubt the development of such high voltages seems a useful technical purpose, from the purely scientific point of view interest is mainly centred on the application of high voltages of these high potentials in vacuum tubes in order to obtain a copious supply of high-speed electrons and high-speed atoms. So far, we have not yet been successful in approaching, much less surpassing, the success of the radio-active elements, in providing us with high-speed alpha-particles and swift electrons. The alpha-particle from radium-C is liberated with an energy of 7·6 million E.V. The swiftest beta-rays from radium have an energy of about 3 million volts, while a voltage of more than 2 million would be required to produce X-rays of the penetrating power of gamma-rays."

The application of high voltages to vacuum tubes presented serious technical problems, but these were being attacked by Dr. Coolidge. The old electron tubes used 80,000 volts, at most, to accelerate electrons, and the electrons were stopped by a few inches of air, but Coolidge was using 300,000 volts and the electrons thus accelerated penetrated chrome-nickel iron alloy 0·0005 inches thick.

Above 300,000 volts flash-overs were produced, but these were eliminated by having X-ray tubes in series and

obtaining a supply of electrons at 900,000 volts, corresponding to a current of one or two milliamperes. This intense beam of high velocity electrons was spread out in a hemisphere by the scattering of the metal window of the tube and produced luminescence in air while penetrating two metres of it.

The advantage of this method is that though the energy acquired by the individual electrons in falling through 900,000 volts is less than the energy of the beta-rays, the electrons are far more prolific. A number corresponding to a current of two milliamperes is equal to the beta-rays from about 150,000 grammes of radium in equilibrium; but there was much to be done before streams of electrons equal to the beta-particles in energy could be produced.

Rutherford gave a word of encouragement for further advances. "It would be of great scientific interest if it were possible in laboratory experiments to have a supply of electrons and atoms of matter in general of which the individual energy of motion is greater even than that of the alpha-particle. This would open up an extraordinarily interesting field of investigation which would not fail to give us information of great value, not only on the constitution and stability of atomic nuclei but also in many other directions.

"It has long been my ambition to have available for study a copious supply of atoms and electrons which have individual energy far transcending that of the alpha and beta-particles from radio-active bodies. I am hopeful that I may yet have my wish fulfilled, but it is obvious that many experimental difficulties will have to be surmounted before this can be realized even on a laboratory scale."

Besides high voltages powerful magnetic fields are also required in this work.

The magnetic fields were produced by sending electric currents through coils containing cores of soft iron, their ends or poles being cone-shaped. In this way the magnetic induction was concentrated to a great extent into a small area. The unit of strength of a magnetic field is the 'gauss.' Owing to the limit set by the saturation of the iron, the greatest fields obtainable were of 80,000 gauss over a volume the size of a pin's head, and about 50,000 gauss for 20 cubic millimetres.

Professor Cotton, of Paris, was engaged on an electromagnet requiring a small power station to work it. Its poles were one metre square and it required 500 kilowatts to saturate it. Enough power to supply the lighting of a village of 3000 inhabitants. It would not give more intensive fields than the existing ones, but would produce a field of given intensity over a larger volume. These fields were small compared to what was really required, half a million gauss.

The method for obtaining fields approaching this size originated with Kapitza at the Cavendish Laboratory under the direction of Rutherford. Kapitza had been measuring the heating effects of alpha-particle beams at various points in their range. From his results he had deduced a velocity-range relationship for alpha-particles with results conflicting with those obtained by Blackett. He decided that the discrepancies between their results indicated the use of more direct methods, thus leading him to the development of magnetic fields. A very strong current was sent through a coil for such a short interval that the heating effect in the coil was restricted to a permissible value. These immense currents were produced by short-circuiting a high-voltage condenser through the coil.

Kapitza first employed a special form of accumulator to send a very strong current through a coil for about 1/50th of a second, the current then being broken. In this way it was shown to be practicable to carry out experiments, and on the bending of alpha-particles in magnetic fields of 200,000 gauss, considerably stronger than those obtainable by the ordinary methods. In subsequent experiments a generator of special design was installed which gave a very large current of the order of 70,000 amperes at 2000 volts when short-circuited, and in this way short-circuit periods of 1/100th of a second produced very strong momentary currents.

The chief difficulty was to construct coils strong enough to withstand the enormous disrupting forces which arose with such large currents. However, Kapitza persevered and designed a coil capable of giving a field of 320,000 gauss over a volume of 3 cubic centimetres without any sign of coil fracture. But Rutherford hoped that soon they would be able to reach 500,000 gauss.

For Kapitza's experiments at the Cavendish Rutherford was instrumental in obtaining from the Department of Scientific and Industrial Research a grant which defrayed the cost of the apparatus and the experiments. This enabled special accumulators to be built for the first experiments, and a generator for those subsequent. Also, Sir William Pope kindly provided a temporary laboratory which was opened in 1926 by the late Lord Balfour.

The need for these tremendous fields is explained by Rutherford himself:

" While the application of external magnetic fields of the order of one million gauss will no doubt markedly perturb the orbits of electrons in the outer structure of the atom, it is not to be anticipated that they will seriously affect the stability of the atomic nuclei. General evidence indicates that the magnetic fields within the nucleus are much too great for such a relatively weak external field to cause a disruption of the nucleus. In this direction the bombardment by high-speed particles is likely to be far more effective than the strongest magnetic field we can hope to generate.

" This advance of science depends to a large extent on the development of new technical methods and their application to scientific problems . . . the development of methods of producing high voltages and intense magnetic fields, is not only of great interest to scientific men in itself, but also promises to provide us with more powerful methods of attack on a number of fundamental problems."

CHAPTER XV

EXPLORING THE NUCLEUS

RUTHERFORD'S studies were leading him towards the view that the atomic nucleus was far from being the comparatively simple structure he had thought it to be in 1911.

The possibility of the existence of a particle called the 'neutron' had been visualized; alpha-particles were possibly satellites of an inner nucleus in the nucleus itself, and that protons were acting as a cement within the intense electric *and* magnetic nuclear fields.

Rutherford soon found it necessary to issue a warning against the too ambitious assumption that gold was possibly being produced by transmutation. He said that it was well known that minute traces of gold were to be found in many substances and pointed out that in cases in which gold was said to have been produced from base metals, the gold was, no doubt, there all the time.

The Press had frequently announced claims by a number of people who affirmed that they could change mercury into gold by the passage of an electric current through ordinary mercury vapour. This claim had even been made by German and Japanese scientists.

Actually the small amounts of gold thus transmuted were present to begin with either in the mercury or in the electrodes; when other experimenters carried out precisely the same experiments, after having first taken the precaution of removing all foreign substances from the material, not a trace of gold was found. No method of transmuting metals on any large scale had been proved possible; but even the more scrupulous scientists were not prepared to say that the effect was impossible on a small scale. In any case, as Rutherford so many times said, gold can only be

obtained by the transmutation of the more costly metal, platinum.

Rutherford's 1928 Presidential Address to the Royal Society dealt with the subject of high-frequency radiation of the X-ray type.

Progress had also been made on X-rays and gamma-ray research. Plank's quantum theory had provided the means for calculating the electrical energy required to produce rays of definite frequencies. For example, the energy required to produce waves of the frequency of green light is 2 electron volts ; for ultra-violet light 10 e.v., and X-rays from a few hundred to 300,000 e.v., and more.

At Pasadena a million volts have been used, giving X-rays of 100 feet range in air. But it was not yet possible to obtain X-rays equivalent in strength to the gamma-rays from radio-active substances requiring between 3 and 4 million volts.

On applying Einstein's theory of the relationship between mass and energy to the atom of uranium changing to lead of atomic weight 206 and involving a loss of eight helium nuclei in free state and 0·05 units of atomic mass, we arrive at the result that the energy charge is 46,000,000 volts, far above man's present resources.

The helium nucleus consists of 4 protons and 2 electrons, and has a mass of 4·00216. The mass of four hydrogen atoms is $4 \times 1{\cdot}0078$. Thus the loss of mass in the formation of a helium atom is equivalent to an energy of 27,000,000 volts.

Rutherford said : " If it be possible to imagine that in some ways this energy is emitted catastrophically, in a single quantum radiation, the energy of the quantum would correspond to 27,000,000 volts.

" Similarly the total energy emitted during the formation of any atom of known mass from free atoms and protons may be estimated from the change in mass from 1·0073 to mass 1·000. An energy release of 7,000,000 volts per proton."

Another example : " The atomic weight of the most abundant isotope of mercury is 200·16 containing protons of mass almost 1 and 120 electrons. Thus the energy that would be required to form mercury from protons is about one thousand four hundred million E.V. (1,400,000,000 E.V.).

" When we consider the extreme complication of such a heavy nucleus and the number of its component parts it is

difficult to believe that this emission of energy can take place in one single catastrophic act. It is so much more likely that the energy is emitted in a step-by-step process during the organization of the nucleus. . . ."

Having so far concluded that the base of all matter is composed of seemingly indestructible electrons and protons, we have the voice of Sir James Jeans suggesting new ideas from his studies of the universe. Rutherford said : " But Jeans, to account for the long lives of the hot stars suggested that even the protons and electrons are not indestructible, but may under unknown conditions be transformed into radiation. The total internal energy of the electron is about 500,000 E.V., for the proton 1840 times as great, about 940 million E.V."

Thus, when electrons and protons disappear there is an enormous liberation of energy if, in a single quantum gamma-radiations are obtained equivalent to 940 million E.V. However, Rutherford suggested that it was a speculative hypothesis difficult to prove or disprove directly.

Continuing, Rutherford said : " Apart from radio-active bodies we have no definite experimental evidence of the emission of penetrating radiation, either in the formation of atoms or destruction of the proton, and it may be that the processes considered do not take place under the conditions of our experiment on earth. On the other hand the long life of the hot stars indicated by general astronomical evidence does seem to demand some such process or processes in which the liberation of energy is enormous compared with the mass involved.

" It is thus of very great interest to examine whether any direct experimental evidence can be obtained of the existence of such extraordinarily energetic X-rays."

He then referred to the recently discovered penetrating type of ray called 'cosmic,' with a frequency of 100 to 1000 million times that of ordinary light waves and of intense penetrating power.

It was assumed that these might be high-frequency gamma-rays from space ; but the fact that so much radiation was absorbed by matter made it necessary to consider the factors determining the absorption.

In the case of the heavier elements the absorption of

ordinary X-rays is due to interaction between the radiation and atomic electrons which gain energy from the quantum in radiation. This is the well-known photo-electric effect. A small loss is also due to scattering, but the photo-electric effect predominates.

In the case of gamma-rays the loss of energy from scattering is more important and, for radiation of 100 million volts, almost completely governs the absorption, of which the main feature is the 'Compton Effect.'

The Compton Effect is an occasional interaction between the quantum of radiation and the electron in the atom, whereby radiation is scattered and the electron set in motion.

In the scattering of penetrating rays the frequency of the scattered ray is reduced by half for each scattering collision, when about half the energy, on the average, is given to the recoil electrons. Thus, whenever very penetrating radiations pass through matter recoil electrons of high speed are always present.

The momentum and energy are conserved, and thus the energy given to the electron depends on the nature of the encounter and the angle of scattering. This theory was verified by several direct and distinct methods.

Then several efforts were made by Compton, Klein, and Durac to determine the absorption coefficient of these encounters. Three different results were obtained.

However, Gray, at the Cavendish under Rutherford, made a careful examination of the existing data on the absorption of gamma-rays and informed Rutherford that the evidence as a whole was more in accord with the theory of Klein than those of Compton and Durac.

This was a very important matter, requiring clear proof, and Rutherford wanted it cleared up as soon as possible. However, Millikan and Cameron agreed with Klein for the figure of 940 million volts as the intense energy required, to convert the proton into radiation, although the theories, as Rutherford said, were too uncertain to place much weight upon this figure.

Again, ordinary scattering is supposed to be confined to the extra-nuclear electrons, but with a quantum energy of 1000 million volts it is not unlikely that the nuclear electrons may be effective in scattering, as well. In fact, if the energy

of the quantum is large compared with that required to release a nuclear electron, this effect is to be expected, and, of course, that such powerful radiations or swift electrons liberated by them might disintegrate a nucleus in their path. Thus, Rutherford remarked: "For all these reasons it is evident that much more information is required before we can draw any but tentative conclusions as to the nature of the penetrating radiations of our atmosphere."

He then suggested certain avenues of approach, such as the use of the Wilson Cloud Chamber, and the application of a strong magnetic field, so that the curvature of the tracks of the beta-rays would enable a determination to be made of their individual energy.

Rutherford poured cold water on the popular theories of atomic energy. Fantastic stories had been in circulation concerning a coming discovery of means for 'harnessing' the energy tied up in the atom; lay writers had been giving figures supposed to represent the forces which would be available for the service of mankind if the energy in one single atom could be 'put to useful work.'

He said: "While it is hoped that in the years to come we may have available for study in our laboratories swifter beta-rays and higher frequency radiation than we have to-day, we can scarcely hope in the future to produce artificially, radiations, atoms, and electrons which have an individual energy of the order of 100 million volts, such as are present in our atmosphere.

"It is thus of great interest and importance to use every promising method of attack to throw light on the structure and origin of these penetrating radiations and the effects arising in their transmission through matter. . . . The study of the extraordinary penetrating radiation is not only of great interest in itself, but also for its promise of throwing new light on fundamental processes in our universe connected with the building up and destruction of atoms. It may take years of faithful experiment before the evidence is sufficient to test the correctness of the numerous interesting speculations that have been advanced, to account for the origin and nature of these radiations."

Early in 1929 he opened a very interesting discussion at a meeting of the Royal Society on atomic nuclei.

He contrasted the 1911 atom with that of the present time. Up to that time the nucleus had been regarded as a point; but through the measurements of atom masses, results from collisions of alpha-particles, and natural disintegration of radio-active elements, it had become more complicated. But, as yet, only one weapon was powerful enough for the necessary investigations, namely, the 7 million volts alpha-particle.

Rutherford and Chadwick had been using it in one of the simplest experiments in conception—the observation of the deflection alpha-particles undergo when they pass near a nucleus, yet do not disintegrate it. In this way they obtained information about the fields of force around the target nucleus and that of the alpha-particle nucleus. Thus they obtained direct information on the rate of variation of electrical forces with distance from the nucleus.

From the element copper (number 29) to uranium (number 92) the law of force is the inverse square law, and the closest distance of approach of the particle to the nucleus was found to be 1 billionth of a cm. for copper and 4 billionths of a cm. for uranium. Thus, as there were no deviations of the inverse square law, for these distances of approach the two bodies act as points, no information being deduced about the size of the nucleus except that it was less than this distance.

In the case of lighter elements the particle approaches much nearer the nucleus, and marked deviations from the inverse square law were observed. It was clear that at very close distances attractive forces came into play, varying rapidly with the distance. It was suggested that the deviations were due to distortion or the mutual polarization of the colliding particles and this appeared to provide a general explanation in the case of the lighter elements.

On ordinary views, part of the energy of the alpha-particle ejected from uranium must be due to the repulsion by inverse square law forces, but on applying the results of the scattering experiments, interesting facts came to light.

Rutherford said that if the entire energy of the particle was attributed to this cause (inverse square law), a minimum estimate would be obtained for the distance at which the inverse square law force of repulsion began to be limited

appreciably by a value of 6 billionths of a cm. But this was in disagreement with the value obtained of 4 billionths by the scattering effect. This impasse was, however, avoided by making use of wave mechanics.

The two experimenters had found that in the disintegration of aluminium the change of energy was not the same for each nucleus ; in fact, it varied by as much as 5 million E.V. Thus either the mass of the nucleus or the nucleus formed by the disintegration might vary by as much as 0·006 mass units.

Then Chadwick found that though the probability of the disintegration of aluminium decreases with the speed of the alpha-particle, measurable disintegration is still observed with low-speed particles, and that the scattering effect in other experiments is still due to the inverse square law forces. But, in one experiment, alpha-particles of this speed appear to disintegrate the nucleus, yet in other particles of the same speed are deflected as if the nucleus was a point charge. Both these results are explicable by wave mechanics.

Let us quote Rutherford :

" It is supposed that the repulsive inverse square law field surrounding the nucleus extends down to very small distances of the order of 7/10th of a billionth of a cm. for uranium and soars to a peak value of 30 million volts. The scattering results are therefore directly understandable. The reason why a slow particle can escape from the uranium nucleus or in the other case penetrate into an aluminium nucleus is to be sought for in the peculiar properties ascribed to particles by the wave mechanism. On classical theories, the only way a particle can pass from one region into a second separated from the first by a potential barrier is by surmounting the barrier. On the wave-theory, however, there is a finite probability of the particle passing through the potential barrier, although the energy may be far less than the peak value." The probability of disintegration had confirmed the potential barrier theory.

" Energy is required to disintegrate, and in radio-active atoms," Rutherford said, " the alpha-particle has more mass inside the atom than when it is free."

The loss in mass when the alpha-particle is set free provides part of the energy of the particle.

This was an explanation of radio-active disintegration.

The greater the energy of the particle, the smaller the potential barrier, and greater the chance of escape—disintegration. This is the Geiger-Nuttall law, which gives a remarkable relation connecting the energy of the ejected alpha-particle with the transformation constant.

In July 1929 the British Association met in South Africa, and Rutherford took the opportunity of warning anyone who was trying to discover a new element that he was wasting his time. The analysis of atoms had made it practically certain that no further element existed. Practically every atomic number from 1 (hydrogen) to 92 (uranium) had been identified and Rutherford made the important statement: "*No fractional number was ever known.*"

The next important development was in connection with the alpha-particle. At the British Association meeting of 1930 Rutherford said that he had long suspected that the streams of alpha-particles were complex and, from facts recorded in connection with the gigantic electro-magnet in Paris, that there were at least four groups in the emission from thorium-C.

No doubt ultimately, when sufficiently powerful plant was available, he said, the Paris method would be the best means of analysis. In the meantime he and his workers had applied a simple method by which they had been able to show that the alpha-rays from radium-C were complex; a small portion, about one in a thousand coming off at a different energy level, indicating that the alpha-particles of radium-C occupied a number of energy levels.

This simple method Rutherford had devised in collaboration with F. A. Ward and Wynn-Williams. It replaced the tedious scintillation method of counting, and was based on the principle first shown by Grunacher, of magnifying lineally by means of values the ionization produced in a chamber by an alpha-particle until it could be registered by a relatively insensitive galvanometer. This form of counter could detect a single alpha-particle or as many as 1000 per minute. It immediately revealed the previously unknown short alpha-particles emitted in the dual disintegration of radium-C. These new rays were not homogeneous, and consisted of two groups, a main one of range 4·1 cm. and a subsidiary one of range 3·9 cm.

The particles of 5·5 cm. range from actinium-C were also found to be complex; but the 8·6 cm. particles from thorium-C′, the 7·0 cm. particles from radium-C′, and the 3·9 cm. particles from polonium were found to be homogeneous within the limits of the resolving power of the counter. Thus, it seemed possible that the complex alpha-ray spectra were associated with radio-active elements of odd atomic number. These accurate measurements and the study of the fine structure of alpha-particle emission are responsible for the rapid progress in the study of disintegration from then onwards.

Rutherford's Presidential Address to the Royal Society in December 1930 was on the subject of Intense Magnetic Fields and Low Temperature Research. This address contained considerable news of the activities of the Cavendish and proposals for further research.

In 1921 a young lecturer in physics at the Petrograd Technical Institute had decided to come to the Cavendish Laboratory. His name was Peter Kapitza. In 1922 he began the experiments described in the last chapter.

Rutherford told of the progress that had been made since.

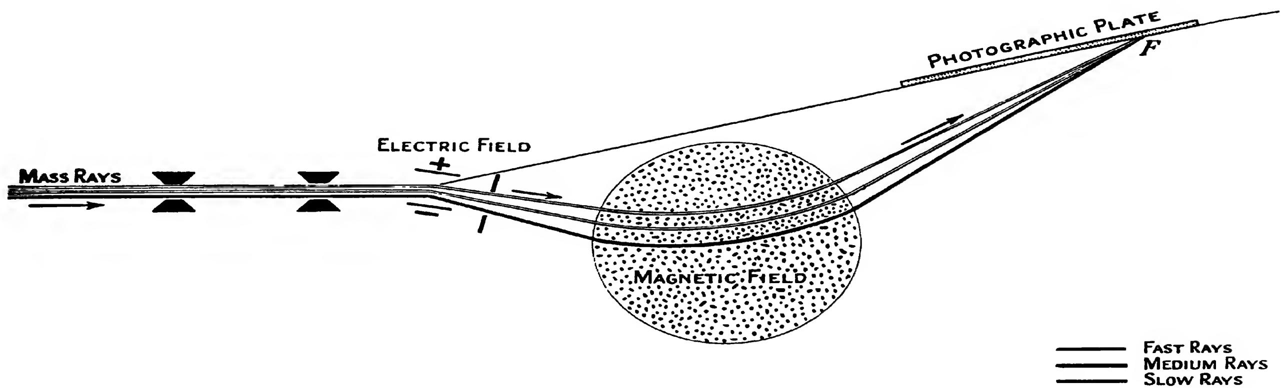
It was extremely difficult to construct a coil strong enough to withstand the colossal disrupting forces due to the enormous currents required for greater magnetic fields of 300,000 to 400,000 gauss now being obtained over a volume of 3 cubic centimetres. Rutherford saw no reason why fields of one million gauss should not eventually be obtained. Although the current was passed through for only 1/100th of a second, a complete quantitative record of the magnetic effects produced in a material over a wide range of field, was obtained in a photograph exposure of 1/100th of a second.

This and other methods had now opened up a new and wide field of research by providing magnetic fields ten to thirty times greater than had previously been available by the use of electro-magnets.

The first experiments were on the change of resistance of crystals of bismuth in these intense magnetic fields from atmospheric temperature to that of liquid air, and then the behaviour of a large number of metals under similar conditions.

Principle of the Mass-Spectrograph

THE DIVERGENCE OF THE RAYS OF DIFFERENT SPEED PRODUCED BY THE ELECTRIC FIELD IS COMPENSATED IN THE MAGNETIC FIELD AS INDICATED SO THAT RAYS OF THE SAME MASS CONVERGE TO A COMMON FOCUS *F*



The mass or positive rays from the discharge tube containing the vapour of an element under electric discharge, pass through a hole in the cathode and are dealt with as described and indicated above. These rays consist of ionized atoms, i.e. nuclei.

These rays either focus to one point, as shown, or to two or more points as the case may be. In the first instance (shown) the element is isotopic in itself and consists of nuclei of identical mass, e.g. Oxygen, 16. In the second the element may consist of a mixture of nuclei of different masses, e.g. Chlorine possesses isotopes of masses 35 and 37 in such a proportion to give an atomic weight of 35.46.

Reproduced by courtesy of the Director of the Science Museum, South Kensington, London.

It was found, in general, that the change of resistance was at first proportional to the square of the magnetic field, but above a certain critical field, which varied for each metal, the change tended to be linear. On the basis of these results Kapitza suggested a new way of looking at the phenomena which underlie the electrical conductivity of metals. At very low temperatures magnetic and electrical phenomena are in their simplest form, because the complications due to the motion of the molecules are largely avoided.

At first liquid air was used, but in 1930 a liquid hydrogen plant was installed and preparations were made at the same time for a liquid helium plant when it should be required.

Although not taking an active part in the investigations, Rutherford made them possible by his directing policy at the Cavendish and his work in securing the necessary funds. It was part of his policy to encourage important lines of work not directly connected with his, as far as accommodation would allow. It was now found that there was a large amount of work to be done in this field, and no space to do it in, so Rutherford set to work to obtain a laboratory.

In his 1930 address he said : " The grant given by the Department of Scientific and Industrial Research expires in a few years, while the laboratory temporarily lent for the purpose of these experiments is now required by the Chemical Department of the University. The Department of Scientific and Industrial Research by its broad-minded and far-seeing action has done a great service to science in thus supporting through their initial stages investigations having no obvious immediate application in practice in industry. Their support for an indefinite period, however, could scarcely be part of the Department's policy. On the other hand, it appeared to the Council of the Royal Society that investigations of this kind in which new fields of knowledge are being opened up by new methods had a peculiarly strong claim for support from those funds which the Society was holding ready for the furtherance of fundamental researches in pure science.

" The Council of the Royal Society, in addition to appointing Dr. Kapitza to a Messel professorship, has therefore agreed to offer the University of Cambridge the sum of £15,000 for the building of a suitable laboratory within the

next few years, provided the University was prepared to offer an appropriate site and defray the running expenses of the new laboratory . . . the Royal Society will thus have been instrumental in founding a new and up-to-date laboratory designed for carrying out researches in intense magnetic fields, but at the same time providing the essentials of a modern cryogenic (low temperature research) laboratory for the study of magnetic and other effects at the lowest attainable temperatures.

"The name of the new laboratory at Cambridge has not yet been settled, but it would be appropriate if it indicated the connection with the Royal Society and the late Dr. Ludwig Mond, whose bequest furnished the income from which the cost of the laboratory will be defrayed. It should be noted that among the purposes indicated in the will of Dr. Mond for the use of his bequest was 'creating new laboratories.'"

Here was a learned society acting on the principles counselled by Phillip Lenard in an essay on Newton.

"We thus again see quite clearly that great advances only come from single personalities and not from societies, no matter how excellent the persons may in general be of which they are composed. Such societies should therefore see their province exclusively in protecting and forwarding the work of the single and all too rare individuals who show themselves to be bringers of progression in any direction."

Rutherford then traced the history of low temperature research from 1900 onwards, and pointed out that Great Britain was pre-eminent in this class of work. Sir James Dewar and Lennox had obtained liquid hydrogen in 1898 and solid in 1899, and devised the vacuum flask as early as 1893. At the St. Louis Exhibition of 1902, a liquid hydrogen plant giving five litres per hour was among the Government exhibits.

He ended his address by saying:

"I am sure that it will be gratifying to the Society to know that we may soon expect to have an up-to-date cryogenic laboratory on a small scale in Great Britain. I believe that it is in helping such important schemes of research that the Society can best utilize any research funds which it already possesses or which may become available in the

near future. It not infrequently happens that a promising line of research or development of a new method may be held up or abandoned because of the difficulty of obtaining adequate financial support. In some important directions advance can only be made with the help of technical assistance in the construction and use of special apparatus, in some cases almost on an engineering scale.

"It is by the encouragement and support of such major researches, especially in their initial stages, that the Society can be of great service in helping the advance of fundamental science in Great Britain. Along such general lines, it is not difficult to foresee that the Society will exert an ever-increasing influence on the progress of science and thus promote still further the original intentions of its founders."

This was the last address given by Rutherford as President of the Royal Society. It is an admirable statement of the progressive spirit of one of the inhabitants of Burlington House, a spirit to which Rutherford had contributed greatly.

In another address Rutherford described the discovery of helium on earth by Ramsay after receipt of a letter from Sir Henry Meiers on 1 February 1895 concerning gases liberated from uranium ores. Ramsay bought a gramme of clevite from a dealer for *three shillings and sixpence*, purified the gases from it, and sent them to Sir William Crookes, mentioning that one of them was unknown and inert and he had labelled it, for the purpose of identification, as 'crypton.' Sir William Crookes, after examining their spectra, wrote to Ramsay: 'Crypton is helium; come and see.' On 25 March 1895 the discovery was announced to the Paris Academy of Sciences. Less than two months had elapsed between the receipt of Meier's letter and the announcement of a discovery of profound significance to the development of physics! And all for three shillings and sixpennyworth of material!

Helium liquefies at 4° Absolute (–269° C.) and solidifies at 1° Absolute (–272° C.). At these temperatures certain metals become super-conductors, showing little, if any, resistance to electric currents. Thus helium was a very important reagent in cryogenic experiments.

Pursuing further their measurements of alpha-particle

ranges, F. A. B. Ward, W. B. Lewis, and Rutherford investigated the long-range particles from radium-C. In addition to the well-known group of normal range of 7 cm. there were found to be at least eight other homogeneous groups of alpha-rays with ranges from 7 cm. to 12 cm. However, their numbers were very minute. For every million 9 cm. particles there were only 17 of the most frequent range (9 cm.).

The experimenters pointed out that there must be some intimate connection between the energy of the gamma-rays emitted by radium-C and these results. The view taken was that the gamma-rays arose from a transition of the alpha-particle within the nucleus between two different energy levels.

The energies of these levels could be found from the energy of the alpha-particles, and it was shown that the differences in energy between these levels and the normal level were in several cases in good accord with the energies of some of the strongest gamma-rays. Rutherford and Ellis made investigations in this direction.

The fact that many alpha-particle emissions consist not of a single particle only, but of a group, implied that the alpha-particle in the nucleus could exist in states of different energy and that it was a reasonable hypothesis that transitions of the alpha-particles between these states occurred in which gamma-rays are emitted, or the available energy is transferred directly to an extra-nuclear electron in the atom. There was strong evidence that energy differences in the alpha-particle groups for a given element were connected numerically with the energy of its gamma-rays.

Their nuclear model they determined was one in which different numbers of alpha-particles are excited to the same quantum state, the exact opposite of what occurs in extra-nuclear electron systems. The formulæ derived from these observations were confirmed by other methods.

Thus it appeared that the gamma-rays were the results of interchange of energy states of alpha-particles within the nucleus.

Continuing their work, they obtained calculations made on the probability of the escape of alpha-particles from radium-C′ and of the average time of transit of the alpha-

particle for different energies of gamma-rays. The strongest alpha-ray group, corresponding to emission of beta- or gamma-ray energy of nearly one and a half million volts, represented an abnormal mode of transition compared with the other groups. The time being very long, R. H. Fowler suggested that the transition is without radiation, the surplus energy being directly transmitted to one or more of the outer electrons of the atom. Many of the lines in the beta-ray spectrum may be a result of similar transitions without radiation. In explanation of the complicated gamma-ray spectrum of radium-C′, it was suggested that more than one alpha-particle in the nucleus may occupy the same energy level.

So Rutherford said: "It is clear that these radiations arising from the nucleus of the radio-active atom represent in a sense some of the characteristic modes of vibration of the nuclear structure. The wave-length and quantum energy of many of the stronger lines in the complicated gamma-ray spectrum have been determined by different methods, with concordant results. It has been difficult to determine with certainty the exact origin of this radiation. It was at first supposed that it must arise from the motions of electrons in the nucleus, but in recent years there has been a growing belief that the radiation is connected with the liberation of an alpha-particle or proton which forms part of the nuclear structure."

Besides the above method the analysis of the 'fine structure' of alpha-particle emission provided light on the problem.

In a transformation the emission of a beta-particle causes a violent disturbance in the parent nucleus, some of the constituent alpha-particles being raised to a much higher energy level than normally. They are unstable there, and after a very short interval fall back to the normal level, emitting their surplus energy in the form of a gamma-ray of definite frequency. Wave-mechanics say that in that short time there is little chance of some of the high level alpha-particles escaping the nucleus. Those that do are the long-range particles whose energy thus gives the value of the energy level it occupied before escape.

The groups of alpha-particles from radium-C were

examined, as we have seen, and the energies of the alpha-particles of each group were determined. Their differences in energy were found to be clearly connected with the energy of some of the most prominent gamma-rays in the spectrum, and the experiments gave strong evidence that the gamma-rays had their origin in the transition of one or more alpha-particles in an excited nucleus.

At the Cavendish, Ellis, in spite of experimental difficulties, confirmed experiments by Rosenblum that though thorium-C emitted rays of identical speed, they possessed a 'fine structure.' Meitner, however, reached an opposite conclusion, and in view of the conflicting evidence Rutherford determined to throw light on the problem himself in another way. He began his investigations in conjunction with Bowden.

Lewis and Wynn-Williams found actinium emanation emitted two distinct groups of alpha-particles, differing in energy by 340,000 volts. Here Rutherford saw his chance. The actinium emanation was carried out from actinium by a current of air into a separate chamber, and the emission of beta- and gamma-rays was tested directly. It was found that the transformation of the emanation was accompanied by weak beta-radiation and strong gamma-radiation. Experiment was in accord with theory, showing that the presence of 'fine structure' is accompanied by the emission of gamma-rays, while at the same time the fact that the rays have their origin in the transitions of the alpha-particle in the nucleus was corroborated.

Rutherford remarked at the time: "It is of interest to consider how far these views can be carried into the region of the artificial disintegration of the elements by alpha-particles. In some of these disintegrations it is necessary to assume that the alpha-particle can be captured in different energy levels, and that the gamma-radiation is emitted as a result of the transition between the two levels. Penetrating radiations have, in the past, been observed in several cases when light elements are bombarded by alpha-particles. Some of these cases are of peculiar interest."

Again by a very simple means Rutherford had solved yet another of the mysteries of Nature.

In 1920, twelve years previously, Rutherford, in the

Bakerian Lecture to the Royal Society, had suggested the existence of the 'neutron.' In March 1931 he had said that the transformation of the atom would occur if an electron could be forced into the nucleus. "Apart from the radio-active bodies," he said, "it now seems clear that a large amount of energy must be applied to produce disruption of the nuclei of the ordinary elements. The old idea that a new source of energy could be tapped by transformation of the ordinary element now seems untenable. There remains, however, one interesting possibility. If protons could be made to combine to form a nucleus of helium an enormous amount of energy should be emitted during this process. Unfortunately, there is, as yet, no evidence that such a combination could be produced under conditions available in our laboratories."

CHAPTER XVI

THE SCIENTIST IS HUMAN

'It is half the battle in life to be enthusiastic about your job.'
RUTHERFORD at a School Speech Day.

THROUGHOUT his career Rutherford was intensely enthusiastic about anything that he had set his mind on accomplishing. His research work, his Chairmanship of the Department of Scientific and Industrial Research, his Presidency of the Society for the Protection of Science and Learning, his home life, or even a public lecture were lived or carried out with that intense enthusiasm to be known for ever as Rutherfordian Energy.

As direct in his progressive march in his particular field of science as was the track of the alpha-particle, he did not, like the particle, decrease in power and strength during his journey, neither did he at any period trace erratic tracks like the beta-particle.

Rutherford was not the typical scientist of popular tradition. He shaved regularly, wore clean collars, and kept his hair trimmed. This is not what the public expects of a scientific genius. It is, however, not fair to blame them for holding such a conception of those whose lives are spent outside the pale of publicity, locked in the comparative secrecy of the laboratory, for the very nature of their work tends to make the smaller scientists aloof from the world and unable to condescend to satisfy the general curiosity that may, from time to time, be displayed towards their work.

Undoubtedly, however, there are and have been many instances of what may be termed snobbery on the part of scientists in their attitude towards the general public and contempt towards the means by which the public becomes informed of the world's doings—the newspapers.

But Rutherford was a man of science above all that. While it is true that he found difficulty in contending with people who did not understand his work—a very excusable thing—he was modesty itself, never adopted a patronizing air and detested all who did. He often referred to such people as 'humbugs.' "After all my years of study and experiment," he said one day towards the close of his career, "I know little more than when I started out."

The following story, told by Tom Clarke, one time News Editor of the *Daily Mail*, and later Editor of the *News-Chronicle*, is characteristic of Rutherford's attitude towards the Press:

"Rutherford was one of the really great men of our time. He will be remembered when many who are front-page news to-day are forgotten. When the news came that Rutherford was going to break up the atom under a helium bombardment at Cambridge, we of the Press got busy on his track. What a talking point! What dreadful things might happen!

"Frightened old ladies wrote asking if it meant the end of the world. Reporters went to the lectures of this modern wizard and came back in tears, asking how they were to make a story for popular reading out of such obscurities as 'atomic nucleus,' 'ultimate constituents,' 'continuous radiations,' and 'ionized gas.'

"Rutherford refused to come down to earth to help them. He had the scientist's horror of being garbled by the lay Press. He saw no 'sensations' in his technical work and refused to depart from the technical terminology of the laboratory. I think he was wrong, as I think many leaders of science are still wrong in holding aloof from the man in the street and not giving simple understanding explanations of what they are doing. After all, it is on the interest of the lay public that the finance of the research really depends.

"*Reynolds's News* was the first lay paper to break the news that Rutherford and his Cambridge assistants had discovered how to split the atom at will. A proof story was handed to him at the Royal Academy banquet late on Saturday night, and he scrawled across it 'This information is generally correct—Rutherford.'

"It was one of the biggest scoops in the history of Fleet

Street. Rutherford was a bluff, hearty fellow with a quite unprofessional laugh, which he released for my benefit when I tried to persuade him to come off his high horse. 'Why,' he replied, 'you fellows would make me look silly, not because you wanted, but simply because you don't know what I'm talking about.'

" 'If I send someone who does?' I ventured.

" 'Wait and see,' he replied, not unkindly, I thought.

" I sent him in turn three people. All returned empty-handed. It was eventually a woman who brought me a wee measure of success. She came one day for a job. I asked her what she could do. Well, she had a Cambridge science degree. That caused me to mention Rutherford. Did she know him?

" Yes; she had had a spell as helper in his laboratory. I told her of my difficulty in getting him to talk for a popular newspaper reading and said that if she contemplated leaving science for journalism, here was her chance to open the door.

" She pulled off quite a nice little story. She got through Rutherford's barrage, not only because he was naturally polite to the opposite sex, but also because he was ever loyal to those who had worked with him and ever ready to help them if he could.

" I reminded him of this incident when I last met him on the other side of the world. He laughed and said: 'I remember how you beat me with a woman, but she did know what she was talking about, which is what most of you journalists don't.' "

Tom Clarke's reference to Rutherford's loyalty to his helpers and his desire to help them could be amplified in scores of ways.

At Cambridge and earlier at Manchester he realized quite clearly that the training of a large number of students must inevitably hamper and act as a brake upon his own work; but he regarded it as a duty, and threw himself into the task of directing their energies and guiding their studies with wholehearted enthusiasm. In fact it was at Manchester that Rutherford first instituted his training class, and the scheme eventually led to a course prepared by Geiger which was eventually published as a textbook and is known colloquially as 'Geiger's Course.' It was the result of

Rutherford's opinion that the training of students in research methods was as important as the immediate advancement of knowledge. He gave the most careful thought to the problems on which he set his students to work, so that they should be within their powers and lead up to profitable lines of research. He kept a watchful eye on everyone, giving help and encouragement, but expecting and at times demanding the best a man could do.

When the time came for a paper to be read he would, as we know, supervise the paper with the greatest care, making what changes in presentation he thought desirable, even to the extent of re-writing whole sections. No paper ever left the laboratory until he was satisfied with it. In fact many a stream of research that bears another name may be traced back to a Rutherfordian source.

In time Rutherford came to regard the training of students in methods of research as of almost equal importance to the advancement of knowledge, and it would be difficult to overestimate his services and his influence regarding the preparation and encouragement of the younger people. There can be few if any universities in the British Empire which do not contain at least one of Rutherford's students.

In previous chapters mention has been made at various points of Rutherford's power in experiment, but this is a subject which can hardly be over-emphasized, for it is impossible not to be deeply impressed with this quality of his. One experiment followed another so directly conceived, so clean and so convincing as to produce in the scientific mind almost a feeling of awe, and experiments came in such profusion that one can only marvel that a man could do so much. Rutherford had, of course, an intense enthusiasm and volcanic energy. His capacity for work was immense. It is true that many a 'clever' man has produced notable work, but Rutherford was not 'clever' in that sense. The quality he possessed was greatness. He had the most astonishing insight into physical processes, and with a few words could illuminate a whole subject.

There is a stock phrase—'to throw light on a subject'—and that is just what Rutherford could do. He seemed to know the answer almost before the experiment was made, and he was ever ready to push on to the next. He was a

true pioneer, at his best in exploring an unknown country, pointing out the important features and leaving the rest for others to survey at leisure.

Chadwick said of him :

" He knew his worth, but he was and remained, amidst his many honours, innately modest. Pomposity and humbug he disliked and he himself never presumed upon his reputation or position. He treated his students, even the most junior, as brother workers in the same field, and when necessary spoke to them ' like a father.' These virtues, with his large, generous nature, and his robust common sense, endeared him to all his students. All over the world workers in radio-activity, nuclear physics, and allied subjects regarded Rutherford as the great authority, and paid him tribute of admiration ; but his students bore for him also a very deep affection."

While to the layman Rutherford's work seemed extraordinarily abstruse and, as Tom Clarke said, barely understandable, his own writings and lectures were regarded by the scientific world as models of clarity. " His arguments," said William Bragg (now Sir William Bragg), " are expressed in straightforward language which reveals the completeness and force of his thoughts. He has the courage to break with precedent and try out his own ideas. Rutherford has upset many theories, but has never belittled anyone's work. He has added new pages to the book of physical science and he has always taught his students to venerate the work of the old, even when the writing has become a little old-fashioned. Perhaps it is by characteristics such as these, quite as much as by his own scientific perception and technical skill, that Rutherford exercises such a wide influence.

" He always takes a broad and generous view, giving credit to others for their contribution to knowledge and never pressing for the recognition of his own. For this reason his students have worked under him with loyalty and affection, knowing that their interests were safe in his hands."

Contrary to the usual conception of a scientific man, Rutherford was an excellent man of business. The directness of thought which was such a power in the laboratory

could be as readily turned on more every-day affairs. He had a sound grasp of the essentials of business, and on such occasions as meetings where progress was slow or problems seemingly unsurmountable, Rutherford would soon take the lead and with his understanding of human beings and his driving-power quickly bring matters to a successful issue. Nothing ever seemed to be too much trouble, and one of the reasons that he surrounded himself with one of the largest and most successful groups of investigators in any laboratory was because he was able to inculcate the spirit of endurance and steadiness essential to the man of science and the research worker.

Rutherford never lost the right opportunities for bettering the facilities of the Cavendish. The experiments of Cockcroft and Walton made it evident that better technique and larger voltages were required necessitating a special laboratory. Just at this period the Cambridge Philosophical Society moved to new quarters and their very convenient site was acquired for Rutherford's intended High Tension Laboratory.

In collaboration with the architect, Mr. Holden, Rutherford planned it carefully and the laboratory soon began to take shape, and though delayed, owing to shortage of material, was ready by April 1937.

Cockcroft and Walton, after consultations with workers concerned, designed new methods for the production of high direct-current voltages. In the end, however, the apparatus was bought from Phillips of Endhoven. They then accomplished the difficult task of obtaining well-focused and well-directed beams of ions of great velocity.

At the time of Rutherford's death the laboratory was in full swing. It is through Rutherford's foresight and business ability that the Cavendish has expanded so much. The main additions are the Royal Society Mond Laboratory, the High Tension Laboratory, the projected Austin Laboratory and the various smaller additions that have already been mentioned.

Rutherford had an unshakable belief in the importance of his work, for though, as he said to an inquirer once, his experiments 'had not produced anything of immediate commercial value,' he knew that there would come a day,

perhaps many hundreds of years after he had gone, when it might be possible for man to make use of the enormous store of energy known to be locked up in the atom. A small incident revealed his attitude towards his investigations. When on his war work he was invited to attend the demonstrations of a French device for locating submarines. He sent word to the effect that he would be delayed by the necessity of completing some work in his laboratory, for he thought that he had succeeded in splitting the nucleus of hydrogen into two parts. " If this be true," he said, " its ultimate importance is far greater than that of the war."

In a sense Rutherford was right, and when the time comes, centuries hence, as Rutherford himself suggested, when a vast source of energy will be placed at the service of mankind, the peoples of that age will remember the name of Rutherford and will regard him as the great pioneer, while the Great War will be, if not almost forgotten, of no more importance in history than are the Punic Wars to us to-day.

The means by which this very tentatively suggested view of the future may possibly be accomplished is by some great development of transmutation.

Transmutation was the crowning triumph of his life's work, says Eve. Rutherford was considerably fascinated by it and regarded his achievement with a quiet satisfaction and enthusiasm which are to be found on reading his *Newer Alchemy*.

Rutherford was a scientist who could see both sides of the supposed struggle between science and religion. He realized the importance of preserving the ethical as well as the material balance of mankind and thought that only by keeping spiritual forces constantly in mind could people be restrained from making the worst uses of scientific discoveries, and using them for destruction and, maybe, the annihilation of civilization. He did not belong to the body of scientists who took the attitude represented by the aphorism 'God retreats as Science advances.'

A remarkable parallel exists between Rutherford and Faraday. Both were experimenters who made very little use of mathematical machinery either in their work or their explanations. Rutherford would say jokingly : " They

(the mathematicians) play games with their symbols, but we turn out the real solid facts of Nature." At the same time his personal qualities were extraordinarily akin to those of Faraday, who by sheer force of will and personality arose from the humblest beginnings to the highest position in the scientific world. Both men were able to draw broad, simple, and comprehensive deductions from complicated and tedious work in the laboratory. While both these men were centres of universal affection, Rutherford differed in one respect. Faraday preferred to work without assistants or students, alone in the quiet of his laboratory; Rutherford sought personal contact and throve on companionship.

His personal magnetism had to be observed to be truly appreciated. His strength of character, honesty, and shrewdness caused him to tower above men of lesser quality.

Many men of science have been giants in the laboratory but have proved veritable pygmies outside. Using the whole of their forces upon their work, they have had little left for the ordinary process of living. So great, however, was the store of energy which Rutherford possessed that he was able to throw himself with zest into the simplest mundane matters, bringing his breezy manners and indomitable good humour to bear on every-day affairs. He had a deep and resonant voice, which went well with his robust figure, and he could be amused at trifles.

In fact, so wide was Rutherford's influence during the Cavendish period as his insight and sound judgment became widely appreciated that the claims on his time and services became very great. He was consulted on awards and appointments by societies, universities, and Government departments. All these activities were carefully carried out with the inevitable result that his own scientific contributions suffered to some degree since in later life he was not able to give them continuous Rutherfordian attention.

Of his home life a friend once said: "All memories of Rutherford are happy, but for me there is none happier than the memory of him sitting with wife and friends, relaxed after a day of exercise, before a blazing fire; when he would talk, as he loved to, of great campaigns in military history or (best of all) recount some incident in his own campaigns of scientific discovery. It was well to remove the clock;

that done, and Rutherford in the mood for talking, one could count on hours of sheer delight. He would tell us of talks with Kelvin in days when a young man's notion of atomic structure had still to win acceptance ; of his first lecture at the Royal Institution ; of battles fought with academic opponents in the early days of his professorship.

" To speak of his devotion to science would have been to invite his sarcasm, for he was ever scornful of ' these fellows who take themselves so seriously ' ; and the word may seem inappropriate of one whose leisure showed such zest for talk and friendship, such love of easy laughter and the banter of his friends. Yet he lived for his work as few men really do, and I think that this was the reason why he sometimes expressed disinclination for the intimate friendship which can make inroads on a man's independence. His instinct was for friendship that takes no harm from temporary separation, and to this friendship he invited men of all types and ages. It did not matter that you were not eminent or if you were ; provided only that you were not pretentious you would quickly find yourself on terms. So we had come to count on him in a world where few things seem sure."

At his cottage in Wilts., curiously enough a part of New Zealand farm, Rutherford would heartily enjoy himself in outdoor occupations ; bathing, motoring, or tree-felling, in company with a few of his closest friends.

When Rutherford was raised to the peerage in 1931, becoming Baron Rutherford, it is noteworthy that he took pains to have a Maori and a kiwi embodied in his arms, this being the first time that either of these Antipodean symbols had appeared in the Royal College of Heraldry.

It was, however, the Vienna Academy of Science which was one of the first bodies to appreciate the genius of Rutherford, and in connection with this academy there is an example of Rutherford's greatness of heart. In 1908 the Academy lent him 300 milligrammes of radium free of cost. This greatly assisted him in his work. After the war it seemed that this radium, which was still in Rutherford's hands, would be confiscated as ' enemy property ' ; but after a lengthy correspondence he succeeded in getting the preparation released. Six years later, in 1927, he learnt that the Vienna Academy was in financial difficulties, and

he helped them by purchasing the radium and so enabling research to be carried on in Vienna for some time.

In the autumn of 1925 Rutherford managed to make a six-months' visit to Australia and New Zealand, particularly to his old home and to Christchurch where he was presented with an illuminated address. Although received with great honour and esteem the people of Australia and New Zealand found that he was still one of them. Just like a good hearty pioneer farmer of the kind that laid the firm foundations of those Dominions. He never lost a chance of looking-up the friends of his youth and spending much time with them and recalling past rugger battles.

He was intensely fond of his mother, and his first action on being raised to the peerage was to telegraph :

> 'Now Lord Rutherford. Honour more yours than mine. Love. Ernest.'

It must be mentioned that amongst unusual distinctions Rutherford had the honour of having an L.M.S. Railway locomotive named after him.

CHAPTER XVII

THE FULFILMENT OF A PROPHECY

"EVERY day I grow in girth *and* in mentality," bellowed Rutherford one day when he was being measured for a shirt.

The knowledge about the atom was expanding. The last stage of Rutherford's career had begun. Perhaps the most astonishing of all. Now came the true reward of all his efforts; a reward which consisted of two great discoveries made in the spring of 1932.

While examining the artificial disintegration of light elements under the action of alpha-rays, Bothe and Buscher had noted in 1930 that beryllium did not emit protons under alpha-ray bombardment like boron and nitrogen, but gave a weak radiation which was more penetrating in character than the gamma-rays. Later on, Mme Curie-Joliot, M. Joliot, and also G. Webster examined the absorption of the rays by matter.

Using polonium as the source of alpha-rays, it had been found that when hydrogen nuclei were exposed to the new radiation from beryllium, swift protons were emitted. The explanation put forward was that the protons gained their energy by a radiation recoil similar to the Compton Effect, the quantum energy of the radiation being estimated at 50 million E.V.

Using direct counting methods of great sensitiveness, Chadwick found swift recoil atoms were liberated not only in the passage of radiation through hydrogen, but also in other light elements.

Chadwick proved that the rew radiation ejected particles from the elements hydrogen, lithium, beryllium, carbon, air, and argon.

The particles resembled protons in their speed and ionizing power. On further examination, all kinds of

discrepancies crept in on assuming that they were protons, but on assuming that they were neutral particles of " neutrons " everything in the garden was lovely.

Rutherford's prophecy had been realized.

On being interviewed, Rutherford stated that he did not confirm the assumption that had been made, that these particles were matter in the everyday sense of the word, neither from the fact that their collisions obeyed the laws of momentum, nor for the further assumption that they moved at a speed of more than 1/10th that of the velocity of light.

Meanwhile Chadwick had been cautious in his statements. He said that the result of his experiments in search of the particles called ' neutron ' had not at the moment led to anything definite and the element of doubt about its ultimate discovery still existed. . . .

Chadwick acknowledged his debt to Rutherford by describing his experiments as the normal and logical conclusion of the investigations of Lord Rutherford ten years previously. Positive results, he said, in the search for the neutron would add considerably to the existing knowledge on the subject of the constitution of matter and as such would be of great interest to science, but to humanity in general the ultimate success or otherwise of the experiments being carried out in this direction would make no difference.

Rutherford said :

" It is to be anticipated that a projected neutron would produce little if any ionization in its passage through matter, and would pass freely through the outer structure of atoms. A simple neutron should, however, indicate its presence by the recoil of the atomic nucleus with which it collided. This recoiling nucleus would spend part of its energy of motion in ionizing the gas and should thus readily be detected by its electrical effect. . . ."

The neutron is in simple words a neutral proton, a positive hydrogen nucleus interlocked with a negative electron in stronger combination than the ordinary proton and electron in the hydrogen atom. Rutherford described the neutron later :

" The passage of the invisible neutron into the nucleus of the atom is like an invisible man passing through Piccadilly

Circus; his path can be traced only by the people he has pushed aside."

It was also found that the neutron in colliding with an electron produced an electron track of maximum length corresponding to twice that of the velocity of the neutron.

Cloud chamber tracks of the neutron were photographed by G. N. Feather, more than a hundred recoil tracks in nitrogen being obtained. Here a very interesting effect was observed. In addition to the straight recoil tracks there were a number of branching tracks, indicating that the nitrogen had disintegrated in a novel manner. Rutherford believed that these branch tracks were produced by the recoiling nucleus and by some particle which was ejected from the struck nucleus, but at the time he was unable to identify the latter particle definitely.

"It will take a long time," he said, "to analyse the results obtained and to examine the effects produced in other gases. The peculiar properties of the neutron allow it to approach closely, or even enter nuclei of high atomic number, and it will, for example, be of much interest to decide whether the neutron is captured in such disintegrating collisions or whether it has such a catastrophic effect."

It was Rutherford's opinion that whatever might be the final explanation, it was clear that the results obtained from Chadwick's work were due to a quantum of radiation and that it would either be necessary to relinquish the laws of the conservation of energy and momentum in the production of that radiation and its interaction with matter or accept the neutron hypothesis. In any event, it was evident that the new discoveries had opened up a new region of research of great interest and promise.

Following this discovery, which made memorable the spring of 1932, others were on their way.

On 2 February 1932 Cockcroft and Walton announced that as a result of the high potential laboratory that had been developed at the Cavendish, steady potentials of 800,000 volts at a current of a milliamp had been obtained.

Using this power, they accelerated protons artificially to a velocity of nearly 12 hundred metres per second, resulting in them having a range in air of 13·5 mm. at 710,000 volts.

They next bombarded a layer of lithium with a stream

of these protons and examined the result through a screen which absorbed all stray protons. A number of bright scintillations were observed on the zinc sulphide screen which increased to many hundreds as the voltage increased from 125,000 to 400,000 volts. The new particles had a range of 8 cms.

Further evidence suggested very strongly that these were alpha-particles.

What had happened?

The lithium of mass 7 must have broken up into two alpha-particles of mass 4 and 8,000,000 e.v. energy.

In other words, Cockcroft and Walton had *split the atom.*

Thus in April 1932 Cockcroft and Walton announced the results of an experiment that has gained more attention from the popular Press than any other of the century. It was the climax of three years' work on the apparatus.

In these experiments Cockcroft and Walton had maintained a steady potential up to 600,000 volts, producing a stream of protons corresponding to a current of 20 microamps., and a little later Lawrence and Livingston in California produced a stream of protons with an energy of 1,200,000 volts by the multiple acceleration of charged atoms, using a voltage as low as 4000.

Cockcroft and Walton's apparatus could give protons speeds comparable with those of alpha-particles and in far greater numbers than the particles from radio-active elements. So long as these elements remained the sole source of high-speed particles, there was no possibility of producing large-scale disintegrations. But now this possibility had been born.

The mechanism of the work was simply that the energy store binding the nucleus together was liberated by the intrusion of a proton into the private life of the nucleus. This resulted in its disruption and the liberation of alpha-particles with 100 to 160 times the energy of the proton.

It appears at first sight that the dream of industrial science had been realized; at last man could avail himself of the immense stores of nuclear energy.

Such expectations were but dreams. Rutherford pointed out: " After the ingenious romancings of the Press, which has stated, in various forms, that we should be able to produce an immense accumulation of added electrical energy for commercial purposes, we cannot claim that for

our experiments up to the present, for the simple reason that for every particle of additional energy we get, it requires millions of particles to make it effective. The experiments are, however, of great scientific interest and are likely to be powerful agents in extending our knowledge of the atom."

Within a few weeks Cockcroft and Walton had found that several elements were capable of being disintegrated, providing much useful data.

They found that lithium, boron, and fluorine, $4n+3$ type of elements were most readily disintegrated, while aluminium and carbon very much less so, and beryllium, calcium, cobalt, nickel, copper, and silver slightly. Also, uranium, itself disintegrating naturally, was capable of being artificially disintegrated.

The further work had made certain that some of the products of the disintegration were alpha-particles, and it was these which scintillated on the screen.

The energy released was about 17 million volts, which agreed with theory.

The disintegration was explained by the fact that a nucleus of the $4n+3$ type captured a proton from the accelerated particles and a new alpha-particle was formed inside the nucleus. This unbalanced state of affairs lead to the rupture of the new nucleus into its component parts.

"The development of this work," to quote Chadwick and Eve, "owed a great deal to Rutherford's steady support and enthusiasm. He took little interest in the technical side of the work or even the actual achievement of producing a beam of high-speed protons. His only interest was in the application of the apparatus to the object for which it had been built."

One can, perhaps, do no better than end this chapter with the words of the late J. W. N. Sullivan with which he closed his essay on Lord Rutherford:

'Atomic energy is as yet far from being available for the uses of human life. But centuries hence it will probably become available as a vast source of energy at the service of humanity, and the people of those future centuries will look back to Rutherford as the pioneer who led the researches which ultimately made atomic energy available.'[1]

[1] *Great Contemporaries—Essays by Various Hands*, Cassell, 1934.

CHAPTER XVIII

HIGH VOLTAGES AND HIGH SPEEDS

THE 'splitting of the atom' opened up another vast field for scientific enterprise. It was to be the last phase of Rutherford's career.

In 1931, Anderson, of Pasadena, Cal., thought he had discovered the positive electron, i.e. a positive particle of approximately the same mass and size as the negative electron, as the result of experiments on the cosmic rays. Rutherford had previously suggested the possible existence of such a particle.

Blackett and Occhialini at the Cavendish confirmed this, examining the radiations in an expansion chamber. Then experiments by the Curie-Joliots with neutrons caused Chadwick, Blackett, and Occhialini to consider the possibility of positive electrons being produced in the interaction of neutrons and matter, and they obtained definite evidence that they might be.

From further evidence it was therefore assumed that their mass and magnitude of charge was the same as for the negative electron. At the time the manner of their production was not clear. They were shown to be heterogeneous.

Meanwhile, in the U.S.A., a new form of generator was being evolved requiring no transformer or rectifier, and it was hoped to reach a potential of ten million volts with it, giving a lightning flash 50 feet long. It was being built by Van der Graaf; first as an outdoor apparatus, giving 1,500,000 volts, consisting of two globes fifteen feet in diameter connected by a vacuum tube. When describing it, Rutherford said: "I leave it to you to imagine the perspiration and profanity that will be needed in its erection, and no doubt many of my old students think I am very conservative in not providing them with such an apparatus."

The main theme at the Cavendish was artificial disintegration. Efforts were concentrated on artificially accelerated particles, the neutron, and the properties observed on their respective disintegration of elements.

The alpha-particles from the disintegration of lithium were found to consist of two groups differing widely in speed. The transformation of lithium could take place at as low a voltage as 30,000, with the number of particles rising rapidly with increases in voltage.

Protons were also remarkably effective in disintegrating boron, emitting two alpha-particles, the disintegration being represented by:

$$^{11}_{5}B + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He + ^{4}_{2}He$$

The top number before each symbol represents the atomic mass of the atom, and the lower number the charge of the atom of the element.

The radiation emitted was found to be complex. A number of other elements were found to be transformed under the same conditions and in all cases with the emission of alpha-particles.

The apparatus used was developed and a new type of accelerating tube designed by Oliphant at the Cavendish, capable of giving a narrow proton stream generated up to voltages of 200,000, and a thousand times as intense as that in the original experiments.

This very new sensitive method was used to determine whether the heavy elements, lead, bismuth, and uranium showed any clear evidence of transformation. Contrary to the results of the first experiments, no sign of the emission of alpha-particles was observed. At first, marked effects were observed, but these were found to be due to boron contamination which were probably responsible for the positive results observed by Cockcroft and Walton.

Generators giving vast quantities of protons were now required.

In California, Lawrence, using a potential of less than 10,000 volts, obtained protons of energy 1·5 million volts by multiple acceleration, and he hoped eventually to reach 10 million volts or more.

"Even if the new projects prove successful," commented Rutherford, "the speeds of particles produced by their aid must be lower than those where electrons and protons of energy from 200 million to 2000 million volts are present."

Describing the rapid progress that was being made, Rutherford said: "In a sense we are opening up to-day a new branch of knowledge—nuclear chemistry—where we deal with the combinations and dissociations not of atoms as a whole, but of the ultimate units which make up the minute world of the nucleus."

The development of this new branch was astonishingly rapid.

Many wild imaginative statements were being issued by ill-informed persons.

While delivering the British Broadcasting Corporation's National Lecture in June 1933, Rutherford said: "It has sometimes been suggested, from analogy with ordinary explosions, that the transmutation of an atom might cause the transformation of a neighbouring nucleus, so that the explosion would spread throughout the material. If that were true we should long ago have had a gigantic explosion in our laboratories with no one remaining to tell the tale. The absence of accidents indicates, as would be expected, that the explosion is confined to the individual nucleus and does not spread to neighbouring nuclei; Taking the radius of the nucleus as a unit, the other nuclei are relatively far removed from the centre of explosion."

Then again at the British Association Meeting in September 1933: "We might, in these processes, obtain much more energy than the proton supplied, but on the average we could not expect to obtain energy in this way. It is a very poor and inefficient way of producing energy and anyone who looks for a source of power in the transformation of atoms is talking moonshine."

He and Oliphant investigated the efficiency of transmutation processes of several elements.

They found that boron and fluorine disintegrated, while iron, oxygen, sodium, and aluminium did not; neither did the heavy elements, gold, lead, bismuth, and uranium.

It was assumed that the disintegration of boron mass 11 occurred by splitting into the 3 alpha-particles, and it was

suggested that the most probable mode of escape of the alpha-particles was symmetrically with equal velocities. On this basis they calculated a range distribution curve for the emitted particles, which was in agreement with the curve observed ; from this they interpreted that the energy available was about 9 million E.V., while from the calculation from the masses it was 11 million volts.

Blackett announced at the meeting of the British Association in 1933 that the positron had been detected by the study of cosmic rays by the Wilson cloud-chamber method. In conjunction with Occhialini he had discovered the existence of the cosmic 'showers' whose effects appear so beautiful when they are rendered visible by the cloud chamber. The particle's mass and charge were comparable to those of the negative electron and it did not differ from it by more than 50 per cent and it appeared to originate in some type of atomic or nuclear process brought about by the incident cosmic radiation.

The positron had also been found when radiation from a beryllium target was bombarded by alpha-particles, while the Curie-Joliot's measurements suggested that it was produced by hard gamma-rays rather than by neutrons, because the gamma-rays from thorium-C were absorbed by heavy elements. Probably, therefore, the positrons played an important part in the anomalous absorption of gamma-rays.

Thus, another constituent was added to the 'bricks' that formed the structure of the atom. There were the electron, the alpha-particle, the proton, the neutron—and now the positron. How many more 'bricks' were there?

"As to the prospects of obtaining further knowledge of transformations in the near future," he said, during a broadcast lecture, "while it is dangerous to prophesy in science, the main lines of attack are sufficiently clear to look, at any rate, a short distance ahead. . . . There seems to be little doubt that by the use of still faster particles of different kinds . . . we might hope in the next few years to observe the transmutation of some of the heavier elements on a small scale. A successful method of attack on the general problem has now been opened up and extraordinary powerful yet delicate devices are available for studying

the diverse effects which might arise during the transformation. . . . As one whose scientific life has been largely devoted to investigations on the structure and transformation of the atom, I watch with much interest and enthusiasm the development of these beautiful experiments to add to our knowledge of the constitution of nuclei. No one can be certain what strange particles or unexpected phenomena may next appear. I know of no more enthralling adventure of the human mind than this voyage of discovery into the almost unexplained world of the atomic nucleus."

CHAPTER XIX

MODERN ALCHEMY

'Our congratulations are due to our American colleagues for the masterly way they have opened up and developed so rapidly this new field of knowledge, which it is certain will prove of great scientific and practical importance in many directions in the near future.'

RUTHERFORD, 1933.

FOR more than a century scientists had looked upon pure water as a well-defined chemical substance, H_2O, of molecular weight 18.

About 1930, confidence had been slightly disturbed by the discovery of the isotopic constitution of oxygen, whose isotopes were found to be of atomic weight 17 and 18. Thus, water had molecules of molecular weight 19 and 20 as well as of 18.

Birge and Mendel found a slight discrepancy, about 1 in 5000 between the ratio of the masses of the atoms of hydrogen and oxygen as measured by Aston by the positive-ray method and the ratio deduced by direct chemical method. They suggested that this discrepancy might be due to the presence of an isotope of hydrogen, mass 2.

Urey, Brickwedde, and Murphy decided to test whether the presence of ^2H (to use its symbol) could be detected by direct optical methods. The experiments were successful in showing a small trace of ^2H, estimated at about 1 in 4000 of the ^1H isotope.

Rutherford, discussing the new hydrogen, said: "We have no definite evidence of the exact constitution of ^2H, whether it should be regarded as a simple entity or built up of two or more constituents. It was at first natural to suppose that the ^2H nucleus might be made up of two protons and a negative electron, but subsequent discovery

of the neutron indicated that it might rather be a close combination of a neutron and a proton. Taking Chadwick's value of the mass of the neutron as 1·0067, the nucleus is slightly less, 2·0136, indicating that the binding energy of the neutron and proton combination is slightly less than one million volts. If this be the case, it is to be expected that the ^2H nucleus should be broken up by collisions with a swift alpha-particle."

Rutherford and Kempton tested this, but were unable to detect with certainty the presence of any neutrons when heavy water was bombarded with alpha-particles. Rutherford concluded that if the disruption of ^2H with an emission of a neutron occurs, it must happen very rarely compared to the number of violent collisions between alpha-particles and ^2H nucleus.

The American physicist, Lawrence, found that when matter was bombarded with high-speed ^2H ions, a group of protons of nearly the same speed was released from a number of elements, and he suggested that the ^2H broke up into a neutron and a proton, either in the bombarded nucleus or in the strong electric field in its neighbourhood.

The unexpected behaviour of heavy hydrogen gave rise to several speculations. If the Law of Conservation of Energy was to hold, then the mass that Chadwick had found for the neutron should be placed much lower—1·0006 instead of 1·0067, giving heavy hydrogen a store of energy corresponding to 5,000,000 volts to be released in nuclear collisions.

Next, Rutherford found that the fields of force near the ^1H and ^2H were sensibly the same.

The method by which heavy hydrogen was first found is very interesting, and the method is still the best for obtaining large supplies. Old electrolytic cells were found to contain a comparatively great concentration of heavy water, and Washburn and Urey found that the residues were rapidly enriched with heavy hydrogen after electrolysis. Lewis and MacDonald used this method on a large scale at the University of California, obtaining a concentrated preparation of heavy water. Normally, about one atom of heavy hydrogen is present to some 6500 atoms of ordinary hydrogen. Since the escape of ordinary hydrogen in a sodium hydroxide

electrolyte is five or six times faster than that of heavy hydrogen, relative to their concentration in solution, there is a steady accumulation of heavy hydrogen in water until nearly pure heavy water is obtained. About six litres of ordinary water are required to produce one cubic centimetre of heavy water.

Jocularly, Rutherford once told an audience : " Put 125 amperes through a cell day and night and you electrolyse one litre of water. Then repeat the process over and over again until you have nothing but heavy hydrogen. It is an expensive business, but anyone with a little money can do it."

Lewis and his collaborators determined the physical properties of this new water. Its density was 11 per cent higher than that of ordinary water, its freezing point 3·8° C instead of 0° C, boiling point 101·42° C, and its maximum density at 11·6° C instead of 4° C.

" Heavy water," said Rutherford at a Royal Institution Lecture, " has the same appearance as water, but if you were to have a bath in it you would float. . . ."

Rutherford said : " It is obvious that this new discovery opens up a wide and important field of work. On account of its greater mass it is to be expected that the rate of diffusion and the rate of chemical reaction will differ when ^2H is substituted for ^1H, while compounds formed with the new isotope are to be expected in some cases to exhibit rather different properties from the normal hydrogen compounds."

When he first prepared nearly pure heavy water, Professor G. N. Lewis very generously distributed samples to a number of investigators in the United States and Europe, and with that presented to him, Rutherford was able to make some important experiments.

Very happily Lawrence had his apparatus for producing high-speed ions of more than a million volts energy, and he found that the heavy hydrogen ions were much more effective in many cases than protons of equal energy in causing transformations of new kinds in elements, giving in some cases alpha-particles with a speed considerably greater than the swiftest alpha-particles from radio-active substances.

At the Cavendish, Dee and Walton examined the reaction in a Wilson chamber and found that the lithium nucleus of mass 6 broke up into two alpha-particles, these escaping in nearly opposite directions.

Rutherford and Oliphant examined the action of ^2H on the lithium isotope mass 7 and found the result rather complicated, since the alpha-particles were liberated over a wide range of velocities. Apparently the nucleus broke up into two alpha-particles and a neutron, which may have an energy as high as 15 million volts.

Rutherford confirmed this by finding that neutrons could be detected in numbers corresponding to this mode of transformation, using ^2H particles of energy of about 200,000 E.V. It was also found by others that a copious supply of neutrons could be obtained by bombarding beryllium with ^2H, while Lawrence obtained large numbers from lithium with very fast ^2H particles. He inclined to believe that most of the neutrons observed in his experiments arose from the break up of the ^2H neuclcus into a neutron and a proton.

Again, Cockcroft and Walton transformed many light elements, using ^2H fast particles of about 500,000 E.V.

With great rapidity had the United States physicists at California University opened up this new field of activity, energetically doing the spade-work that is always required before intricate and specific researches can be carried out. Rutherford often spoke of his gratitude to them.

Once again looking into the future, Rutherford said: "There can be no doubt that this projectile . . . will prove of great service in studying the processes which take place in the transformation of the elements, and thus will give further important information on the structure of the nuclei."

Some discussion arose about the name of the new isotope. Urey proposed the name 'Druterium.' Lewis suggested 'Deuton' or 'Deuteron.' Said Rutherford: "While the name 'deuton' is in some ways suitable, it has, for me, the objection that it is liable in the spoken word to be confused with 'neutron,' especially if we have a cold. . . ."

Rutherford then suggested 'diplogen' for the atom of

heavy hydrogen and 'diplon' for the nucleus, adding that the symbol D might be allotted to it. However, after the terms 'diplon' and 'diplogen' had been used in Great Britain for a time, 'deuteron' and 'deuterium' superseded them.

Rutherford and Oliphant investigated the transmutations effected by deuterons. Inorganic hydrogen compounds had their hydrogen replaced by deuterium, and were first bombarded by an intense beam of protons. Nothing extraordinary happened. They behaved like ordinary hydrogen compounds; but when a deuteron beam was substituted, there was an enormous emission of fast protons from the compounds, even at energies of 20,000 volts. At 100,000 volts the effects were too great to be observed on the instruments. The protons had a range of 14·3 cm.—an energy of 3,000,000 volts. In addition, there were short range groups of single charged particles or range about 1·6 cm., in number equal to the first group and also a large number of neutrons of 3,000,000 volts energy.

In a letter to *Nature* in March 1934 Rutherford said: 'It seems to us suggestive that the deuteron does not appear to be broken up either by alpha-particles or by proton bombardment for energies up to 300,000 volts. It therefore seems very unlikely that the deuteron will break up merely in a much less energetic collision with another deuteron. It seems more probable that the deuterons unite to form a new helium nucleus of mass 4·0272 with two charges. This nucleus apparently finds it difficult to get rid of a large surplus energy above that of an ordinary helium nucleus of mass 4·0022, but it breaks up into two components. One possibility . . . is the reaction

$$^{2}_{1}D+^{2}_{1}D\rightarrow^{3}_{1}H+^{1}_{1}H."$$

The figures previously mentioned agree well 'with that to be expected from momentum reactions for a hydrogen particle of mass 3 and charge 1. The mass of this new hydrogen isotope calculated from mass and energy changes is 3·0151.'

Rutherford had found evidence for the presence of yet another hydron isotope—'Triple' hydrogen. Events were

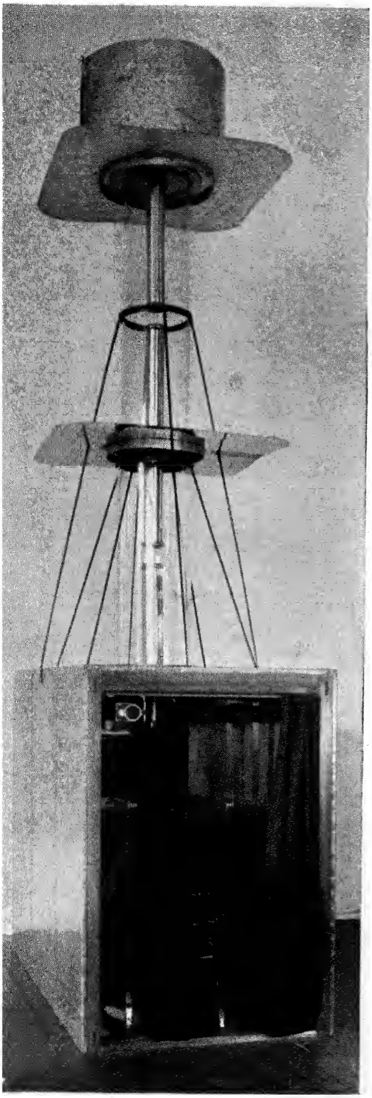


Fig 1.

ckcroft and Walton's Apparatus for the Artificial Disintegration of the Elements.

Reproduced by courtesy of the Director of the Science Museum, South Kensington, London.

Note.—The metal stav rods and collars

A

B

Fig. 2.

A Wilson Cloud Chamber photograph of the splitting of a lithium atom into two alpha particles ejected in opposite directions 'A' and 'B.'

Other alpha-particles from similar collisions by protons accelerated in the apparatus in Fig. 2, partly shown.

Reproduced by courtesy of the Director of the Science Museum and the Royal Society.

moving quickly. 'Another possible reaction,' wrote Rutherford, 'is :

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{2}He + ^{1}_{0}n$$

If this new reaction were correct, 'the mass of $^{3}_{2}He$ is 3·0165, and using this mass and Chadwick's mass for the neutron, the energy of the neutron comes out to be 3,000,000 volts.'

At the time the short range of the new helium isotope—eventually found to be 0·5 cm.—combined with many disturbing factors, made it impossible to detect it in these experiments while the question of their permanence required further consideration.

Rutherford had further suggestions : " It is quite likely that the helium nucleus of mass 3 is unstable and may possible break up into triple hydrogen and a positron. . . . It is of interest to speculate why the heavy isotope of hydrogen appears in many cases far more effective, for equal energies, in producing transformations than the lighter isotope.

" On the general theory of transformation proposed some years ago by Gamow, it is to be anticipated that, for equal energies of motion, the deuteron, on account of its heavier mass would have a smaller chance of entering a nucleus than the swifter proton. It may be, however, that normally only a smaller fraction of the protons which actually enter a nucleus are able to cause a veritable transformation, the others escaping unchanged from the nucleus. On this view the greater efficiency of the deuteron in causing transformation may be due to the fact that a much larger fraction of those which enter the nucleus are retained by it, leading to a violent disintegration of its structure. It may be, too, that the deuteron on entering a nucleus breaks up into its component parts. The appearance of the proton as well as the neutron in some transformations may be connected with the composite structure of the deuteron."

In May of the same year, the existence of the hydrogen isotope of mass 3 was confirmed by the mass-spectrograph analysis of a heavy hydrogen sample.

At the International Conference of Physics in October 1934 Rutherford made the interesting suggestion that a

possible line for experiment in the future was the use of lithium, oxygen, and other nuclei as bombarding particles.

In 1933 M. and Mme Curie-Joliot made a 'sensational' discovery of great significance. They found that the bombardment of certain light elements by alpha-particles gave rise to radio-active elements which broke up on their own according to the same law as governed natural radio-active bodies, emitting not alpha- or beta-particles but positive electrons.

Discussing this production of 'artificial' radio-active elements, Rutherford said, some eighteen months later: "As one of the old guard who has been engaged in radio-active research for nearly forty years, I am greatly interested in the new discoveries. It is sometimes asked: 'Why were the old radio-active people so blind as not to discover these properties?' I have not, myself, been so blind as to overlook the possibility of induced radio-activity, nor, I believe, had Mme Curie. When I went to Cambridge in 1919 I bombarded aluminium, lead, gold, and platinum with gamma-rays in the hope of bringing about such effects. It was the invention of the Geiger-tube-counter which make possible the success of the present investigation."

Fermi (that theoretician of the deepest dye who had suddenly been transformed into an experimenter) and his collaborators in Rome found that a large number of elements gave artificial radio-active elements on being disintegrated by neutrons because the neutron could penetrate the heavy nuclei owing to its lack of charge, when alpha-particles would be turned back.

The first element that the Curie-Joliots found to give a radio-active element on disintegration was boron. This element was bombarded for a few minutes and continued to show marked activity for an hour or so after it had been removed from the bombarding source. The products, strangely enough, were high-speed electrons. Rutherford said that it seemed clear that the reaction was:

$$^{10}_{5}B + ^{4}_{2}He \rightarrow ^{13}_{7}N + ^{1}_{0}n$$

$$^{13}_{7}N \rightarrow ^{13}_{6}C + \text{positron.}$$

"The nitrogen isotope (mass 13) does not exist in nature," he said, "and is transformed slowly into the stable isotope of carbon mass 13. Its decay value is 14 minutes."

Chemical methods confirmed that the radio-active body was an isotope of nitrogen.

"Even the heaviest element, uranium," said Rutherford, "when bombarded with neutrons gives rise to at least four new distinctive types of radio-active bodies, with half-periods of 15 seconds, 40 seconds, 13 minutes, and 100 minutes respectively."

The mechanism was not the same with each element, though in all cases the neutron was captured, and sometimes alpha-particles or protons were emitted ; but generally the higher isotope was formed which was unstable and emitted negative electrons. Cockcroft at Cambridge and Lawrence in America found production of radio-active bodies occurring sometimes after fast proton bombardment.

"It seems clear," remarked Rutherford, "from these results that we are able to greatly increase our knowledge of the isotopes of the elements. None of the radio-active bodies are found in nature, but represent unstable types of isotopes with a very limited life. During the last few months it has been found that the efficiency of the process can be increased in some cases about 100 times or more by slowing down the neutrons."

Improvements in technique proceeded apace at the Cavendish. By means of a complicated apparatus and the use of high potentials of 1,000,000 volts bombarding particles were artificially produced in an electric discharge and speeded up, so that a stream of particles equivalent to the alpha-particles expelled from thousands of grammes of radium was obtainable.

Using this apparatus Cockcroft and Walton obtained, by bombarding carbon with protons and deuterons, radio-active nitrogen similar to that obtained from boron, but with a half-period of 11 minutes instead of 14.

Rutherford summed up the position in these words :

"We can build heavier elements from lighter, and break up other atoms into fragments and produce novel radio-active elements by the score. This new field of what may be called nuclear chemistry is opening up with great

rapidity . . . a very promising beginning has been made. Future work may disclose many surprises, for new and unsuspected particles may come to light. In any even we are entering a no-man's land. . . ."

Then with his usual caution:

"Our idea of the structure of atomic nuclei is still in a very tentative state, but it is generally believed that the proton and neutron are the primary building units. Much more information is required before we can hope to reach a satisfactory explanation of nuclear structure, and any detailed theory applicable to the nucleus is probably far distant."

Again, at the British Association Meeting in September 1935 he said:

"But though an enormous amount of new facts have been discovered in the last year, their theoretical interpretation is still difficult. . . . Thus knowledge grows but wisdom lingers, and we are still without a real theory of the nucleus. . . . However, it is always a happy state in science when the experimenter is ahead of the theoretician, and it may be confidently predicted that great advances in our understanding of the intimate construction of matter are just round the corner. Physics indeed shows no sign of slackening in the rapid and indeed sensational advance begun with the turn of the century."

Rutherford thought that the new radio-active isotopes must exist in the sun and other hot stars where nuclear bombardment was constantly proceeding, and therefore they existed in the substance of the earth when it was first flung off the sun. In course of time they progressively disappeared, and only those with the longest lives remained, radium and its products, for instance.

The prospect of the utilization, commercially and medically, of the artificial radio-active substances appeared rather remote until Lawrence announced that by very intense bombardment of radio-active sodium for twenty-four hours at a high voltage, he hoped to obtain a quantity of the element as active as a gramme of radium. Eventually he succeeded.

By 1935, fortunately, the novelty of discovering new artificial radio-active elements and isotopes was wearing thin. Many new problems had appeared. Rutherford was

particularly interested in the energy relations involved in these reactions, and in a series of collaborations with Oliphant obtained many interesting results. In fact the accurate measurement of kinetic energy changes in these transformations led first of all to Aston's revision of his scale of atomic masses determined by his mass-spectrograph. A small error had been made in determining the mass of helium relative to oxygen. The proton was now 1·0086.

The correction helped matters considerably.

The importance of mass in energy relationship is explained as follows.

The nineteenth century recognized the relations between heat and energy; the twentieth, the fundamental relations between mass and energy as formulated by Einstein in 1905 as a consequence of the theory of relativity. On this principle mass and energy are equivalent, mass being regarded, in a sense, as a concentrated source of energy.

For example, when a rifle bullet is in flight it weighs slightly more than when stationary because of its additional kinetic energy; similarly the mass of a heated body increases in virtue of its additional energy in the form of heat. Of course, in such cases the increases are infinitesimal; but when particles such as the proton, the electron, and others —particles moving at a tremendous speed—from 20,000 miles a second to 186,000 miles a second—are considered, the increase in mass due to kinetic energy is important and significant.

In the ordinary way the mass of the electron is 1/1840 that of the proton, but at the speed given it by cosmic ray action it has a mass greater than that of the hydrogen atom. Thus the destruction of mass involves the appearance of a corresponding amount of energy. For example:

Mass	*Energy*
Mass of electron, 1/1840 of the proton is equivalent to	500,000 E.V.
Mass of the proton (Mass 1)	930,000,000 E.V.
Therefore a mass of 0·001	1,000,000 E.V. (approximately.)

If as a consequence of a transformation, said Rutherford in the 1936 Watt Lecture, the resulting masses of the particles

are less than before, then, if the laws of energy are to hold, the liberation of energy, in any form, " must be equivalent to the change of mass."

In the reaction

$$^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He$$

from a measurement of the speed of the particles and allowing for the kinetic energy of the bombarding proton, it is found that the total kinetic energy liberated is 17·1 million volts, equivalent to a loss of mass of the system of 0·0181 units. The relative masses of the atoms were all carefully measured by Aston and Bainbridge, 'and were found to be H 1·0078, He 4·00216, and Li 7·0146. The difference in the sum of the masses on the two sides of the equation, namely, 8·0224 and 8·0043, is 0·0181. This is in complete accord with the mass equivalent of the kinetic energy released.'

'It is thus clear that the conservation of energy, taking into account the change of mass, holds for this nuclear reaction within the limit of experimental errors.'

It should also be remembered that the law of conservation of momentum and of nuclear charges equally holds. In the above reaction the released energy appears as kinetic energy, but in the case of lithium (mass 7) being bombarded by protons, the greater part of the energy is released as a quantum of high energy or gamma-rays (hv).

$$^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{8}_{4}Be + hv$$

or

$$\rightarrow ^{4}_{2}He + ^{4}_{2}He + hv.$$

The quantum energy of the gamma-radiation is very great—16 million volts, the value to be expected by theory.

" While it appears," said Rutherford, " that, in general, the energy released in a reaction is mainly in the kinetic form, it is of great interest to find such a clear case where the energy can be released in the form of electro-magnetic radiation of high quantum energy."

While the law holds in small cases associated with massive

particles, 'it is by no means certain that the law holds when light particles such as positive or negative electrons are liberated in transformation. It is to be expected that the electron should ordinarily be expelled with identical speed, but in all cases examined they are found to be released with a wide range of velocity, as first observed in beta-rays from radio-active bodies.'

The explanation put forward by Rutherford in the Watt Lecture brings in a prophecy that has not yet been fulfilled. " So far as our information has gone," he said, " it appears that the conservation of energy applies if the energy of the fastest electrons is taken as a measure of the energy lost by all the nuclei involved. Either the conservation of energy does not hold with light particles as electrons, or part of the energy is carried off in some unknown form. For this purpose a new particle called ' neutrino ' has been invented. This particle has no charge and small mass, is supposed to be emitted with the electrons and share part of the momentum and energy, but we have no direct evidence of any kind of the existence of this hypothetical particle. This apparent break-down of the law of conservation of energy is of very great interest and may prove of fundamental importance."

The discovery of the positron gave rise to a remarkable phenomenon. It is produced in certain transformations and by the passage of very high energy gamma-rays through matter. It has a very short life and disappears to coalesce with a negative electron, and the mass represented by both disappears in a blaze of radiation. At slow speeds the combined mass is equivalent to 1,000,000 volts, and on disappearing gives gamma-rays of 500,000 volts quantum.

" This," said Rutherford, " is the first time that evidence has been obtained that matter, or at any rate individual massive entities, can be produced by the action of radiation. There is some indication that this materialism can be effected by high frequency electrons. Under certain restricted conditions it thus appears that mass and energy are mutually convertible. So far no evidence has been obtained that the mass of the proton can vanish into radiation. If this process can occur, the total energy of radiation emitted should be nearly 1000 million volts. It

appears in general that the conversion of mass into energy or the conversion of energy into mass are most likely to take place when we are dealing with very concentrated sources of energy such as occur in the energetic particles in the cosmic rays. Some of these are of far greater energy than we can hope to produce in the laboratory, so a close study of the effects produced by cosmic rays may give us further information on this most fascinating and fundamental problem."

The scale of knowledge in the world of radio-activity had reached such a stage that 'the subject of radio-activity had, indeed, been born anew and had entered again on a new and vigorous phase of life.'

"The opening of this territory," said Rutherford, "has only been made possible by the development of new and powerful electric methods of producing intense streams of bombarding particles with high speeds and by the improvement of the automatic methods of counting swift particles."

It might be mentioned that among the improvements in the methods of producing fast particles was the institution of the improved cyclotron of Professor Lawrence. This piece of apparatus had the advantage over the earlier kinds of possessing a window from which an intense beam of deuterons at 6,000,000 volts could be emitted.

With this instrument Lawrence bombarded bismuth and obtained on its transmutation an isotope of the metal which was radio-active and emitted beta-particles. Its decay period was exactly the same as for radium-E, giving rise to an alpha-ray product identical with polonium (radium-F). The mechanism appears to be

$$ {}^{200}_{83}\mathrm{Bi} + {}^{2}_{1}\mathrm{D} \rightarrow {}^{201}_{83}\mathrm{Bi} + {}^{1}_{1}\mathrm{H}. $$

In the natural transmutations radium-E is an isotope of bismuth. 'This proof of the production by artificial methods of one of the natural radio-active bodies is of great interest and importance.'

By March 1937 practically all the known elements had been found capable of transmutation on a small scale when bombarded with fast particles of a suitable type. By the use of slow neutrons nearly a hundred new artificial

radio-active substances had been discovered, most of them breaking up with the emission of alpha-particles.

Among the interesting discoveries in that field were those of Haber and Meitner, who bombarded uranium with neutrons and obtained trans-uranic elements having chemical properties similar to those to be expected from eka-rhenium, eka-osmium, eka-iridium, and eka-lead, atomic numbers 93, 94, 95, and 96 respectively. Three new radio-active series are formed, two of which arise from the main isotopes of uranium (mass 238) after capture of a neutron, and the third from a less abundant isotope of uranium (mass 235). The natural activity of uranium is not affected by the bombardment.

The production of artificial radio-active isotopes of known elements and the 'eka' elements, all of which are unstable, suggests that when the earth broke off from the sun they existed in the earth, but disappeared as the earth cooled down, uranium (92) and thorium being the sole survivors, because their half-periods of transformation are very long compared with the age of the earth.

The last important research undertaken by Rutherford was a search for the isotopes of hydrogen and lithium of mass 3.

He thought that by the electrolysis of heavy water they might be obtained, as was hydrogen isotope of mass 2.

Spectroscopic examination failed to detect its presence in heavy water. By use of a sensitive form of mass spectrograph charged molecules of TD were found (T = hydrogen isotope mass 3 or triterium) at a concentration of 1 in 1,000,000 after the initial volume of ordinary water had been reduced to 1 part in 225,000.

Professor H. S. Taylor electrolysed 75 tons of water down to half a cubic centimetre, thereby reducing the volume to $\frac{1}{150{,}000{,}000}$ of the original. The amount of T in ordinary water was thought to be about 1 part in 10,000 million.

At Cambridge, Oliphant and Harteck found that the bombardment of a deuterium preparation by fast deutons led to two transformations, one releasing triterium, the other helium of mass 3. From energy considerations it was concluded that the masses of each were 3·0171, hydrogen

atom = 1·0081. The general evidence suggested that both the isotopes are stable under normal conditions, but, however, quantities of these isotopes were required before their properties could be fully determined.

The general attempt to obtain T in quantity was undertaken by the Norsk Hydro-Elektrisl Knoelstofaktieselab of Oslo, Norway, in conjunction with Dr. Oliphant. If it was present then T_2O would concentrate on the electrolysis of heavy water which was concentrated by the electrolysis of ordinary water. Under favourable conditions 43·4 kilogrammes of heavy water were electrolysed (D_2O content 99·2 per cent) for nine months and a half until it occupied a volume of only 11 cubic centimetres. Part of this concentrate was sent to Aston at Cambridge, for him to examine by his precision mass spectrograph for the presence of triterium.

Aston could find no trace of triterium present in the sample. This seemed to be conclusive, since about 13,000 tons of water had been concentrated down to less than half an ounce.

The American observers had obtained a positive result, indicating a proportion T to D of 1 to 10,000 in their enriched sample, but Aston's more direct methods failed to confirm it.

Rutherford remarked : " It is a striking fact that while in transmutation experiments using counting methods the bombardment of deuterium by deuterons the reaction is on a marked scale, giving rise to very large numbers of ^2H ^3H and ^3He particles, yet it does not seem feasible at the moment to obtain sufficient quantities of these two interesting isotopes to study their properties by ordinary physical and chemical methods."

With this unanswered problem before him Rutherford was suddenly taken from our midst.

He ended his Henry Sidgwick Memorial Lecture with the following words :

" The information we have gained on transformation processes may prove of great service too in another direction. In the interior of a hot star like our sun, where the temperature is very high, it is clear that the protons, neutrons, and other light particles present must have thermal velocities sufficiently high to produce transformation in the material

of the sun. Under this unceasing bombardment there must be a continuous process of building up new atoms and disintegrating others, and a stage at any rate of temporary equilibrium would soon be reached. From the knowledge of the abundance of the elements in our earth we are able to form a good idea of the average constitution of the sun at the time, 3000 million years ago, when the earth separated from the sun. When our knowledge of transformations is more advanced we may be able to understand the reason of the relative abundance of different elements in our earth, and why, on the average, even numbered elements are far more abundant than odd-numbered elements. We thus see how the progress of modern alchemy will not only add greatly to our knowledge of the elements, but also of their relative abundance in our universe."

Rutherford's life work has enabled us to understand much of the inner workings of nature. The revolution that took place in our conception of the atom was due to him. From being regarded as a hard spherical body of the pre-1895 period, the atom is now to us 'just a flimsy whisp,' to use Rutherford's words, containing little matter and much space.

CHAPTER XX

THE RUTHERFORD *MÉNAGE*

ONE evening, in the year 1904, a well-built, fair-haired young giant faced a distinguished audience of scientists at the Royal Institution. He was only just in his thirties. In a direct manner tempered with a certain innate modesty and diffidence, this young man shot at the audience new and startling theories as to the powers and possibilities of radium. The audience itself was greatly impressed by this young man with the large moustache and fiery eyes. A year or so previously he had shocked the conservative scientists with the Disintegration Theory, but little was known about him as a personality.

Certain sections of the Press realized the importance of his utterances and duly reported the more sensational. Rutherford had become a newspaper personality. Until his death, and even after, the more dramatic side of his work was regularly reported.

Clearly 1904 was the year in which Rutherford captured the public imagination. However, though much has been written on his discoveries and other work, little has been told of Rutherford—the Man.

The smiling, shrewd face that was the usual portrait, concealed a great individual.

Who was this individual? Who was the real Rutherford behind the force that created the unique position he held? Who was the 'Colonial farmer' who strode successively along the streets of Montreal, Manchester, and Cambridge?

These questions appear easy to reply to at first sight, but to anyone who knew him well they provide only the meagre foundations of the portrait of the true Man.

Let us take an incident that reveals the power of Rutherford's character.

The stage is set in the main hall of a provincial University. The hall is filled to overflowing except for the first few rows which are reserved. On the platform are a table, a magic-lantern screen, a reading-desk, and a gilded sphere that represents an atom. Behind the table are two rows of arm-chairs.

Suddenly there is a movement at the back of the hall and the audience stands up while a six-foot, well-built man, in evening dress, walks down the aisle, attended by the Principal and the Professor of Physics. He leads a procession of academic splendour.

Even while he is walking to the platform and wearing his pleasant smile the audience feels that he is not an ordinary personality.

The audience sits, and the professors arrange themselves in the arm-chairs, and the assistant staff in the reserved front seats.

The smiling figure is introduced to us as Sir Ernest Rutherford. We are told he is to lecture on the atom. Most of the audience sit back and prepare for boredom—less than half know the difference between an electron and a proton.

Rutherford starts to speak. A few words of introduction are given in a most jovial voice. A joke, a few words of slang, and the audience wakes up. The academic atmosphere is shattered. Rutherford has the audience in his power for the rest of the evening. Everything else has dwindled. Rutherford's figure seems to fill the hall. He radiates personality.

The evening ends as a great success with much hilarity between Rutherford and the students at the back of the hall, without any playing to the gallery, as it were.

His audience—they are his now—disperse, saying: "I always thought scientists were odd people"; "The atom, after all, appears to be a very simple affair"; "Most enjoyable lecture I've ever been to," etc. etc.

A man who can capture stiff 'intellectual' audiences in such a manner possesses more, much more, than appears on the surface. He is a human being in all respects and understands the mind of a human being.

The real secret, however, rests in Rutherford—the Man.

* * *

Rutherford's personal appearance belied his real attitude to the world. Behind his bucolic, open-air appearance was concealed one of the keenest minds of his day. As the girth of Rutherford's figure increased with the years so did the keenness of his mind.

Many men of great academic brilliance place a misunderstanding on the word 'humour'; for them it is really wit. With Rutherford it retained its full meaning. He was able to find humour in the most impossible material and thus humanize it.

His bluff exterior determined the spirit that does not care two hoots for insincere criticism but listens only to the sincere. It was that of a man who speaks his mind, not in the domineering manner of a blusterer, but in a tone that varies to suit the occasion and is always friendly and persuasive. He was above all a truly tactful man who cleared the air with definiteness and could propagate views and ideas where a lesser person would only have brought things to a disastrous conclusion.

He would say, for example, to one type of audience: Electricity is not a fluid, it is not even juice, it is atomic—so now you know!"

To another he would draw a picture that all could understand. "If a grain of salt is enlarged to the size of the earth, a cricket ball will represent an atom."

In the first case he captured the imagination of students and in the second a schoolboy mind. The student appreciated the slangy way he would make points clear. The popular audience caught on to his ideas through the everyday similes he employed.

In every way Rutherford was a great practical psychologist.

To all intents and purposes Rutherford appeared as an extremely self-possessed individual, even in the most delicate and trying circumstances. This was merely a protective suit of armour, for underneath we find a very deep sensitiveness which gave him the intuitive mind of a genius.

* * *

Many a man well on the road to immortality has just failed to reach his goal because he has married unfortunately.

His life partner has failed to pull her weight. There are, too, many cases in which an unhappy marriage has acted as a goad. In that case a genius who might be called 'blighted' has been the result. Happily, Rutherford married a working partner. He married, as a wise man should, the right woman, at the right time; a woman who was capable of being a life-long companion.

His marriage took place when he was about to exhibit his powers to the scientific world. It was a trying period, just when he required the helping hand that only a woman can give.

Again, his marriage was the outcome of an engagement of several years' standing. The romance began during his years at Canterbury College. The future Lady Rutherford was a co-student at that institution, and soon after his arrival at Cambridge in 1895 Rutherford announced his engagement. However, they had to wait until 1900 before Rutherford could return to New Zealand to claim her.

Their wedding day was the commencement of a long and intimate partnership. Lady Rutherford was his greatest ally. She was the power behind the scenes in the Rutherford *ménage*.

Few men have had the fortune to find a better partner. No man ever had to worry less about domestic matters. Lady Rutherford took control of all activity in that line, even to the extent of choosing their homes. An easy home life gives a man 50 per cent more capacity for work.

Lady Rutherford is a fair, shy woman, lacking all artificiality. She is outspoken, often almost brusque in her address. In fact she has a directness that is to be valued.

Unlike the wives of many geniuses she was not just a faint background. In atomic terms she may be described as having been the essential neutron of the Rutherford system; not seen, but very necessary for his well-being.

Rare was it to find her accompanying her husband to the many social functions it was incumbent on him to attend. She dislikes the social world. Once she described herself bluntly: "I am not a society woman at all. I go about very little. Why should I, really? I have travelled so much with my husband, and my work and my interests are here at home."

Indeed, she is essentially a home-loving woman.

When Rutherford travelled abroad, however, his wife always accompanied him, and on his holidays, proving an enlivening companion.

She believes in a reasonable amount of relaxation, which she regards as being supremely important for ensuring good health and a keen and active mind. Being out in the fresh air is her favourite method of acquiring it. Gardening is her hobby. The inhabitants of Newnham Road, Cambridge, or for that matter, her neighbours in Montreal and Manchester, were soon accustomed to seeing this clear-eyed, rosy-faced woman trot about her garden, weeding and bending over borders. Delphiniums were her special care and passion. She took great pride in their cultivation. Once the Rutherfords had settled in their new house the garden was soon developed.

Like her husband, she has an intuitive mind and can grasp the fundamentals of some new theory he was attempting to formulate in his mind. Rutherford could discuss his work with her, knowing that the abstract workings of his mind would be fully understood without the necessity of concrete explanation.

The choosing of their Cambridge home, Rose Cottage, shows to a great advantage her romantic and feminine mind, at the same time throwing a most delightful sidelight on her character.

One day, when the Rutherfords were living in Manchester, Lady Rutherford and her daughter Eileen travelled to Cambridge, where Eileen was to sit for an examination at Newnham College.

It was necessary for them to stay in Cambridge several days. One evening the two of them wandered down to the river, behind Newnham Road. Strolling along the bank, they came to an old Regency house standing alone and empty in a derelict garden. The place appeared forgotten and forlorn, yet seemed full of friendliness and character. The paths were overrun with weeds, the grass was over a foot high. The windows were curtainless and empty. Yet, in spite of appearances, there was something in the spirit of this house that made the woman and girl fall in love with it at once.

Finding a gap in the hedge the two made their way in and wandered about the garden. The atmosphere cast a spell over them. Every corner of the forlorn garden was explored. They peered through the windows and examined all the ground-floor rooms. It was their ideal home. Plans were made to make the place habitable and neat. They thought of the property as their own. How they begrudged the future owner his possession!

As often as possible during their short stay in Cambridge they visited that beloved old house, and it was with many sighs that they returned to Manchester.

In 1919 Rutherford went to the Cavendish and the household had to move to Cambridge. Lady Rutherford went ahead to choose their future residence. The first thing she did was to visit the house with which she had fallen in love. By some miracle it was still empty! But not for long.

Joyfully Lady Rutherford went to the agent and negotiated for it at once. The first words she said when she entered it for the first time were: "It is like coming home."

Few houses have been chosen so romantically. Lady Rutherford's intuition had chosen for them an ideal residence, quiet and peaceful, looking out over the grass and the river and the Cambridge spires.

* * *

The private secretary of a man like Rutherford must possess an ability to see just a little into the future; he or she must be able to fathom the workings of Rutherford's mind. Above all, the secretary must be a specialist in Rutherford's scientific field.

Such a secretary cannot be produced at will by any of the usual schools, but must be trained by the employer. Then, after a period, the secretary, for some reason, leaves, and the trouble starts all over again.

Rutherford was fortunate even in this respect. He had married his future secretary. From the time of their marriage in 1900 until his death in 1937 Lady Rutherford performed all the duties of a private secretary. She typed his scientific papers, prepared his manuscripts, filed his cuttings, indexed his speeches, lectures, and papers. Being

a graduate of Canterbury College, she fully understood the activities of the academic world besides the world outside. Rutherford possessed the perfect secretary, a secretary who knew exactly what he wanted.

Lady Rutherford has the capacity for the careful detail of being a great man's wife.

Rutherford's position in the Academic and Scientific Worlds provided him with many vital University and National duties, besides an overwhelming amount of work, which, unless taken systematically, were liable to produce confusion.

He planned his work and avoided the confusion. Much of the burden was relieved because he claimed that he always 'knew a good man when he saw one,' and was thus able to delegate much important work to others.

His life was well organized. A typical day in his life ran something like this :

He would arrive at the laboratory about 9 a.m. and work until one o'clock. Then he would take two hours for lunch, just a normal, light one. After some relaxation he would start work again at 3 p.m. and work until six in the evening. After dinner he would chat for a time with any close friends he had invited, until half-past eight, when he would go to his study and work until ten-thirty.

Whenever possible he saw to it that he had eight hours' sleep in twenty-four. It was his favourite stimulant to prepare himself for further work.

Though hearty in his manner, it was that of a clever, jovial man rather than the heartiness of a hail-fellow-well-met type. Behind it all there was an honest shrewdness that showed itself in the depths of his twinkling eyes, indicating that his breeziness and geniality was a natural perquisite inherent in his make-up.

The calm, temperate mind that viewed science in such an even light continued to exercise itself in his general life. He took alcohol only now and again when the occasion demanded, and then sparingly. Cigarettes did not attract him, but he was a confirmed pipe-smoker and would smoke any tobacco. Seldom did he voice his views on alcohol, but when he did he advocated its stringent control, or, if that was not possible, its prohibition.

Rarely ill, he attributed his good health to 'steady work

and plenty of it.' Whenever Rutherford felt that he needed rejuvenating he would go out into the open air. He always spent his holidays in the country.

He was a very keen motorist and had driven continuously for over thirty years. Long before the war he toured European countries in those well-built vehicles that to-day seem caricatures of the modern motor-car.

Near Chute, in Hampshire, exists the hiding-place of the Rutherfords. Rutherford himself was not fond of crowds, so whenever possible he spent his holidays at his country cottage. It was an ideal cottage in this respect. It stood in a field near Upper Chute and, but for the rabbits, he was the sole occupier. Nearby was a wood where Rutherford spent many happy hours indulging in tree felling and clearing undergrowth.

One day a friend motored down to visit him there. When the cottage was at last reached the friend considered that after the gruelling journey his car would stand up to any future endurance test.

The last two miles of the journey were accomplished by traversing a cart track ; just a cart track. As the cottage was approached he came to a hill so steep that it could only be encountered safely, either ascending or descending, in bottom gear. At the end he found a gate and then one of the finest examples of muddy tracks in existence, that led across the field to the cottage. Determinedly he proceeded, and finally reached the isolated homestead.

Everything was fine—until the departure, about midnight. During his visit the back wheels of the car had slowly sunk some depth into the mud. After a few trials he was still stuck, and was finally rewarded with the delightful sight of Britain's foremost scientist, a man who played with millions of volts as if they were toys, leaping around in the rain with a candle frantically trying to release the near wheel, and enjoying himself immensely.

Being a veteran motorist, Rutherford was interested in the everlasting strife between the motorist, the pedestrian, and cyclist. He had his own solution for the problem. " I have often thought," he said, " that if we could only give pedestrians and cyclists rides in our cars, when driving at night, they would take more care on the roads."

His companion hobby to motoring was golf. Rutherford was very keen on this pastime, though he had a somewhat unique method of play. In the atmosphere of the golf club he was able to meet and enjoy the society of non-scientific men.

Within the circle of his more intimate friends some famous matches were played. The degrees of skill of the members of this circle were by no means proportional to their skill in their work. It was for this reason that certain rules of the Royal and Ancient game were altered so that the balance of skill might be adjusted. Rutherford decreed that the weaker player should, on certain stated occasions, be permitted to say ' Boo ' loudly when a more skilled player was making a shot.

In 1930 the man of whom Madame Curie said " he is the one man living who promises to confer some inestimable boon on mankind as a result of my own discovery of radium," was rewarded by a peerage from the King.

Few peers have ever looked the part as did Rutherford on his induction into the House of Lords.

The new peer, broad, six foot tall, with twinkling eyes, grey moustache, shiny hair, ruddy complexion, and the commanding appearance of a soldier rather than of a scientist, made a striking figure. He strode into the Chamber in the full baron's robes, which magnified his personality. On one side of him was Lord Crawford and on the other the scientist peer, Lord Rayleigh. The art and the sciences were paying tribute to each other. In a deep, pleasing voice, Rutherford uttered the words of the oath, after having shown one of his rare indications of nervousness over the first few words.

'For public service,' was the official reason for the inclusion of his name in the New Year's Honours List, and it was nothing more than the truth. Rutherford had little to do with the usual ' reason '—politics. Personally, he professed Liberal beliefs, believing that in sound, well-laid principles lay a compromise between Government and individual initiative. For example, he did all he could to develop the resources of the Government Department of Scientific and Industrial Research and is responsible for much of its present-day powerfulness. This powerfulness

rests, however, on the way in which Rutherford combined the individual research powers of the manufacturer with that of the Department.

The great gift Rutherford possessed for friendship was exercised all through his life. Dr. Johnson's recommendation to us was to keep '. . . friendship in constant repair.' This Rutherford did, and more. The greater his interests became, the more people he met and the more friends he made. There was no apparent effort on Rutherford's part to make a friend. He possessed an uncanny sense of how to be on good terms with the most difficult people without playing-up to them. It can best be expressed as—'It just happened.'

An acquaintance of two-minutes' standing would obtain the impression that he was the one man Rutherford had wanted to meet, and for the rest of his life that man would feel that in Rutherford he had a true friend.

Rutherford was extremely patient with persons with little or no scientific knowledge. When the Ministry of Co-ordination of Defence was formed, Rutherford, as Britain's premier scientist, had many conferences with Sir Thomas Inskip.

'Those who worked with him . . . ' wrote Sir Thomas, 'alone know how valuable his help was. But I could at least appreciate his human, lovable personality, and it was a rich experience to know him.

'He would come and talk to me about the problems on which I wished to consult him in such a way as to put me entirely at ease. He seemed wholly unconscious of the gulf between the vast store of knowledge in his highly trained mind and my complete ignorance of the questions we discussed. Once when a project . . . proved to be impracticable, he gave no hint of feeling that I had wasted his time. . . . His was true greatness without a trace of condescension. . . .'

It was, I think, this complete absence of condescension—unfortunately not often found among a large number of our academic people—that endeared him to all who met him or heard him lecture.

At an international conference of scientists there is often much opportunity for a deadlock due to the many

nationalities and their different temperaments. Many awkward situations have been averted and jealousy avoided by Rutherford walking into the room with a laugh and a genial word to all. In a few minutes all the different temperaments would be calmed and laughter prevail. That magnetic Rutherford touch worked the miracle. If he had not been a scientist, Rutherford would have proved an ideal negotiator in modern international politics.

When Madame Curie visited England at the beginning of this century she met Rutherford and they became firm friends. She was immediately attracted to this young, shaggy Viking of thirty-odd who talked to her about radiation.

She was so impressed by him that she said : " I should advise England to watch Dr. Rutherford. His work in radio-activity has surprised me greatly. Great developments are likely to transpire shortly to which the discovery of radium was only a preliminary."

Rutherford was one of those fortunate people who never made an enemy consciously. There were, however, certain people whom he could not stand. Meeting such a person gave the onlooker the opportunity of observing how highly strung Rutherford was. He always formed a spontaneous judgment of persons, and he could not adapt himself with those few people with whom he did not feel at ease. They were usually humbugs, and he disliked humbugs.

" It's a great thing, Life," Rutherford used to say. " I wouldn't have missed it for anything." Few men have revelled in life as he did. Life was his happiness, and he found it in the finest measure in the world of atoms.

That infectious laughter combined with an immense sense of fun was nearly always on top, even on the most dreary and boring occasions. Rutherford always appeared mentally to scale.

His imagination was great. His power of figurative comparison and analogy was profound. Commenting some years ago on the position of civilization, he gave the following rich picture. " The relation of the world's inhabitants to their environments has been changed almost as much as if they had been endowed with the magical capacities of Djinns in the *Arabian Nights*—slaves of the lamp and the ring."

Again, he jovially refuted the extravagant ideas about transmutation in 1931. "We are not likely to come out of the commercial depression by means of this discovery."

Another time he suggested that we should create 'A Government Prophecy Department.'

In 1929 certain people had the strange idea that the transmutation of the atom would destroy the world, and scared old ladies wrote to the papers about it. This rather tickled Rutherford's sense of humour, and he replied: "There is no need to worry. The breaking up of the atom has been going on for probably 1000 million years and people have not even noticed it, and the world is still safe for democracy."

His lectures were unique. Answering questions or carrying on discussions would provide one with ample opportunity of enjoying his phrasing, his terse sentences, and his magnificent use of slang. His chaff and sense of fun would keep his students rocking with laughter, and at the end they would find that they had thoroughly grasped his teaching. Every difficulty had been fairly met and there had been no playing to the gallery. It was a spontaneous display on his part, just like the alpha-particle emission from radium.

He was an adept at 'wisecracks' and one required great imagination to cap one of his tall stories with a better one. Gossip, in the finer sense of the word, was one of his accomplishments. Many a delightful evening has been spent by his workers at his Cambridge home listening, around the fireside, to his stories about his early days in New Zealand and his struggles at Cambridge, Montreal, and Manchester.

'We felt,' writes A. S. Russell, 'braced and cheered for the next day's work.

'He told us our interest in research in science would keep us ten years younger than our contemporaries.

'He, himself, was a boy at heart. We wondered how he would grow old. We were sure his powers would not fail nor his interests veer. Would he ever retire? Anyway, we knew he would always "look in" at the lab, to see how work went on and to encourage us over difficulties.'

Rutherford's genius had little or nothing to do with intellectual brilliance. It was an insight born to sheer love

of discovery and of years of concentration on special problems. Research was a game in which he never lost his schoolboy joy. For a long time he was alone among physicists opposing attempts at what he called 'a too meticulous accuracy in calculations.'

This attitude was innate. As a Fellow of Trinity College he dined regularly in Hall on Sunday evenings and often brought distinguished and interesting men of science as guests. However, Rutherford's personality made him a leading figure in that society. There was no one less like a traditional Fellow.

In fact, so invigorating, vital and breezy and unconventional was his presence that the diners felt that an hour with him was like a brisk walk on a bracing day. He never camouflaged and would express himself forcibly. "I like a good scrap now and again," he would say.

His unconventionality revealed itself one day when he was the chief speaker at a school speech-day. The usual dry half-hour was enlivened for once. The age-old problem was brought up by him as to whether a head master wears pyjamas or a night-shirt when he retires for the night. Rutherford confessed that that problem had occupied his mind many times when he was at school. However, it was solved for him. Rutherford said :

"My first school, constructed of wood, was burned down and the next one, built of brick, was destroyed by an earthquake. This latter incident provided an answer to the age-old query. I have vivid memories of my head master leading us in our flight from the building with his shirt-tails flying behind him."

That speech-day was one to be remembered by all present. It was extremely bracing.

Tragedy came, unhappily, into the last years of his life. His only child, Eileen, who married Professor R. H. Fowler, died in 1930. The loss came a few weeks before the announcement of Rutherford's barony in the New Year's Honours List for 1931.

He felt the loss very, very bitterly and he never really got over it. However, he found much consolation in the fondness he had for his two grandsons and two granddaughters. He spent many pleasurable hours with them.

His was the nature that children instinctively trusted and loved. His mind was one that understood so well the workings of a child's mind. Again there was no condescension.

His daughter inherited that strange insight of his. Once she asked her chemistry teacher: "If I guess the result right will you let me off the experiment?" Rutherford's insight had let him off many.

Yet he had little liking for mathematics, able master that he was of that subject. He once said: "Leave philosophy to the Scotsman and mathematics to the Continentals—they're better at it."

Americans and Scottish students often had their legs pulled about their accents. This was rather strange in the case of the Scots. The Rutherfords had originally emigrated from Scotland, while Rutherford's title was the revival of that which belonged to an ancient Border family in the Scottish Peerage. Sir Walter Scott's *Bride of Lammermoor* was founded on the tragic story of the love affair of the third Lord Rutherford. The title died in 1724, so Rutherford was quite entitled to assume it again. Now it again remains in abeyance.

Rutherford possessed great business ability and shrewdness. This is much in evidence by the manner in which he managed the funds at his disposal in Montreal, Manchester, and Cambridge. There was little waste with him.

It was again exercised during his Presidency of the Royal Society and he presided over its finances. He did much to improve the financial position at Burlington House.

The Chairmanship of the Department of Scientific and Industrial Research placed at his disposal large funds which he used admirably and enabled some very fine work to be done. He would make small grants go a long way, but he worked on the principle that big work required big money.

His will is interesting. He left a total of £7402. He gave his interest under his father's will as to £100 each to his seven brothers and sisters, and the balance between Georges and James Gordon Rutherford. £4000 and effects to his wife, £50 to his daughter, and the residue to his wife during her widowhood or income from one-half on re-marriage with the remainder to his children or issue.

Rutherford was not, however, to uphold the family longevity. His mother celebrated her ninetieth birthday in October 1932. He died at the age of sixty-six.

Ernest Rutherford can best be summed up in the words of Sir James Jeans, whose recollections of him extend through forty years.

"He was the simplest, most lovable of men, with no enemies: . . . boisterous good nature, ready light-hearted wit, his big personality, and wide tolerant views of men and affairs. . . .

"He succeeded through his own ability, energy, industry, and personality.

"From a flax farmer at the Antipodes to the highest scientific honours and circles in the world."

CHAPTER XXI

RUTHERFORD'S INFLUENCE ON SCIENCE AND INDUSTRY

SIR FRANK SMITH wrote in 1937 : ' It was an article of faith with him (Lord Rutherford) that the future of Great Britain depends upon the effective use of science by industry. It was this faith that induced him, a man of the highest attainment in the field of pure scientific research, to devote himself as he did unreservedly to our (Department of Scientific and Industrial Research) work.'

Early in his career Rutherford had begun to use his influence towards drawing science and industry closer together. His first contact with industry had been, naturally, with electrical engineering, with which pure science had necessarily always kept a close liaison.

In 1926 Rutherford told the Institute of Metals that advance must come through a better understanding of what constituted the properties of metals. " It is remarkable," he said, " how the progress of applied science in many instances depends upon the utilization of some obscure property of matter discovered in the course of purely scientific experiments. For example, in 1888, the brothers J. and P. Curie, working on the properties of crystals, discovered the piezo-electric properties of quartz. In a suitably cut crystal of quartz an electric charge appears on the surface when the crystal is compressed or extended. Conversely, a charge applied to the surface of the crystal alters its dimensions. No one at the time could have foreseen that this property could be utilized to control automatically and with great accuracy the frequency of waves emitted by broadcasting stations and thus be a factor of great importance in reducing interference between stations."

Again : " The discovery about thirty years ago in the

laboratory of the photo-electric effect, in which certain substances exposed to light produce an emission of electrons, has formed the essential basis of the methods used to-day in the transmitting of radio-pictures and in television."

The metallurgical industry had early realized the importance of large-scale research on metals, and from 1917 to 1927 made greater advances in knowledge of metals than in any preceding period since the Bronze Age. This progress continues. Rutherford saw that the future of the industry depended on the metallurgist's close understanding of the fundamental work of the theorist in the laboratory.

In other branches of industry, however, there had been great disregard of the services of the industrial scientist; but in Rutherford there arose a great pioneer and agitator for more and more industrial research. On 1 October 1930 he was appointed chairman of the Advisory Council of the Department of Scientific and Industrial Research, and was answerable only to the Privy Council. In the previous year Dr. Frank (now Sir Frank) Smith had been made secretary to the same council and had also been elected secretary of the Royal Society.

As President of the latter Society Rutherford commented on this dual role by saying: "The Council feel that it is an advantage rather than a disadvantage that Dr. Smith should hold these two posts concurrently; for, although the main spheres of work of the two bodies are distinct, they have many interests in common in fostering the research activities of the nation."

On Rutherford's appointment to the Advisory Council of the Department of Scientific and Industrial Research his tremendous driving force was added to the movement, also the occupants of the two key-posts in pure science were also holding the key-posts in applied science.

At that time there existed amongst research associations that of the British Paint, Colour, and Varnish Manufacturers, which in its four and a half years of existence had done more than its American counterpart had achieved in twenty years.

At a speech to this Association Rutherford told a little story with pointed moral.

"The industry," he said, "is very much older than many of you think, and you are probably not aware how much

your industry has been responsible for modern civilization. A distinguished friend of mine, an anthropologist, once informed me of the use of paste paints by the ladies at the dawn of Egyptian civilization who adorned the features with a paint made from malachite. It is easy to understand how some husband might have become irritated with his wife's adornments and thrown some malachite into a fire. Hence the Copper and Bronze Age! At a later age women were addicted to the use of rouge, and when rouge was thrown on a charcoal fire iron was the result. Hence the Iron Age!

" That kind of argument might be fanciful, but there was one thing of which you can be certain—that the origin of your industry was based on scientific knowledge."

He added that if there was a time when manufacturers should adequately support the scientific side of their work it was then (i.e. 1930), a time of great difficulty. " There would be," he said, " a fiercer competition between the nations of the world in industry, and it was the nation that applied scientific methods most successfully which would succeed."

Rutherford made his maiden speech in the House of Lords in May 1931. The subject was ' Oil from Coal,' and in view of the situation which has arisen since, with continued alarms and risks of European war, it can be said that his speech appears now even more important and far-seeing than it did at the time.

During the previous ten years Great Britain had become a great importer of power in the form of fuel oil, to the tune of £40,000,000 a year.

" It is important," said Rutherford, " to bear in mind that if our supplies of oil are at any time suddenly to be cut short, the greater part of our transport services, the ships of the Navy and the larger vessels of the Mercantile Marine would very soon become immobile. It is obvious, therefore, that it is of great importance to consider carefully the question of the production of oil in this country so as to be independent of other countries."

Rutherford went on to discuss the economic considerations intimately, showing that under the conditions existing in 1931 it was impossible to convert coal, the only source of oil

in Great Britain, into oil and compete on a cost basis with natural oils. But he said that prices would rise in the future, and the future situation would differ materially from that then existing.

He pointed out that although it was not his place to submit a policy to be adopted, a sound policy could only be formulated in the light of both physical and chemical parts and of economic and political considerations.

Rutherford was demonstrating the policy which had carried him so far in the world of pure science and applying it to the world of applied science and industry. There were no fanciful theories ; facts were to be the sole consideration, and he refused to formulate any industrial policy on anything else.

Rutherford then discussed the methods by which oil can be obtained from coal, first, the carbonization method, in which coal is heated and hydrogen at high pressure applied ; secondly, the low temperature carbonization method, in which coal is heated in a retort to which air is not admitted. Then he went into the by-products of these methods.

He mentioned that within the previous years the Fuel Research Department had constructed a five-day retort for low-temperature carbonization, which showed great promise, and said that it was proposed to take up the low-temperature carbonization on a semi-commercial scale to investigate as completely as possible the conversion of coal and coke into oil and to study the by-products.

Then he described the work on the development of low-temperature tars to enable them to replace natural products.

The one certain thing which he said emerged from these experiments was that it was scientifically possible to provide the bulk of our oil by the treatment of tar.

Hydrogeneration was the alternative method and was providing a greater yield of oil per ton than other methods, but the development of both processes in Great Britain would have certain advantages. Carbonization would give a smokeless fuel, but, as Rutherford pointed out, advance, apart from the improvement of technical methods, depended not on science but on how far the nation was prepared to pay for a purer atmosphere.

On the other hand, said Rutherford, the development of

the hydrogeneration method depended also on how far the nation was prepared to pay for its independence in regard to oil supply. To get a full economic benefit, Rutherford indicated that a complete survey of the coal seams of the country was required, since small differences in coal's nature made a great difference in the yield of oil. The Fuel Research Board had been carrying out such a survey for ten years, and it was of vital importance, said Rutherford, that it be continued.

He ended by saying : " It is in the national interest that researches into the general utilization of coal for the production of oil should be vigorously prosecuted. We cannot have too much knowledge of this complicated problem. Research is in essence explanation of the unknown and it is impossible to forecast the results of experiment. Even negative results might in many cases prove as valuable as positive results. They might prevent waste of money in attempts to develop processes. In many respects a full scientific understanding of this complicated problem is more essential to this nation than any other."

That speech was given only six months after Rutherford's appointment to the Advisory Council, and it displays the thoroughness of his knowledge of the subject. All his speeches on industrial subjects bore the same stamp as his pure science writings. He took care to see that he was fully conversant with the intricacies of the various processes involved in the manufacture of such things as cotton, wool, metals, rubber, and with the problems of transport.

When he was on a visit with the Royal Society to the works of Messrs. Spicers, Ltd., the developers of the Sawston colour film process, he said that the long-haired variety of scientific men, who dealt with more or less unpractical things in their laboratories, had a very considerable respect and admiration for the men who could turn their experiments to practical purposes. Then again, " What had been done in the research department of the company had been carried out on a scientific method. It had gone on without blast of trumpets, quietly, in the true scientific spirit of getting a complete article before loading it on the public."

In those few words Rutherford expressed the true ideals of industrial research, and there is no doubt that even to-day

the public does not fully realize the amount of research which goes on before an article maybe costing only a shilling or two can be successfully placed on the market.

Rutherford frequently suggested to one or other of the research associations a scheme of policy, or drew attention to the as yet unused resources at their command. When he opened the new headquarters of the British Non-Ferrous Metals Research Association in June 1931 he said that the quantity and quality of the work which the Association had already carried out during the previous ten years was surprising in view of the difficulties confronting it. It seemed to him that in the future it should divide its work into three categories :

1. *Ad hoc* researches or special investigations bearing on the difficulties of the industry at a particular moment, which might help to improve a product or get over some technical difficulty.
2. Long range fundamental research bearing on matter that lay at the foundation of the industry.
3. Finally, the steady accumulation of knowledge that would lead to the creation of new industries or the development of existing ones, his idea being that an Association of that kind could not take a short view.

These three divisions of labour became more or less the fundamental principles which Rutherford advocated as the policy of all research associations.

He emphasized again the need of close liaison between scientific men and the industries, saying that he regarded it as a most important matter because it restricted the inevitable time lag occurring between scientific discovery and the use made of that discovery by industry. He also pointed out the danger of taking too narrow a view of the value of scientific research. He said that it should be remembered by non-scientific industries that research work could not give definite returns every month.

Then he pointed out that of the 60 or 70 metals available for research work only 6 or 7 had been investigated by the Association. " What about the other sixty ? " he asked. " There is," he said, " probably not a single process that is going on in the industrial world that would not be capable

THE MEN WHO SPLIT THE ATOM

Dr. J. D. Cockcroft (*right*) and Dr. E. T. S. Walton (*left*) with the late Lord Rutherford after the announcement of the success of their experiments.

of improvement if studied scientifically. I am quite sure that 90 per cent of the processes used in industry can be improved by the application of science."

". . . I think that in the years to come only those industries will survive in the world which have shown their power of applying scientific knowledge to improve their methods of production."

On 9 May 1933 Ruthrford made a second speech in the House of Lords. Again he spoke as Chairman of the Advisory Council of the Department of Scientific and Industrial Research. The subject was the Rubber Industry Bill, which was to provide for contributions from rubber manufacturers in the United Kingdom to the Research Association of the British Rubber Manufacturers.

He said that since the war there had been growing recognition of the importance of research in industry. A large number of research associations had been formed in various industries, and he knew from experiences that their work was of very great importance. He estimated that the accumulated effect of the work of the associations amounted to several million pounds annually.

The opponents to the Bill said that the manufacturer being an individual should not be coerced into joining associations, and that industry in this country should work purely on a voluntary basis.

Rutherford went on to say that the Committee of which he was Chairman whole-heartedly supported the proposal of the Bill, although they did not underrate the importance of the voluntary principle. It was, however, essential to continue the work of the associations, so great was its importance.

The Bill was passed by the House of Lords, but owing to the refusal of certain large groups to join on a compulsory basis it never reached maturity.

It indicates the unfortunate fact that many industries which required a considerable amount of benefit from detached research have not the scientifically minded and foreseeing individuals controlling that side of their destinies. This illustrates many of the points raised by Rutherford in favour of compulsory contributing by firms to a co-operative research association. Many of the greatest benefits to

individual industries have been the result of pure scientific research made for no personal gain. It is up to the manufacturers to adapt the knowledge thus gained to their own particular needs.

Voluntary contributions are usually the lowest possible and do not give the best chances for development. Nor do they allow the finance of the Department of Scientific and Industrial Research to be planned on the most useful scale.

In an address to the Chemical Engineering Group of the Society of Chemical Industry Rutherford made many salient points. He spoke of the startling rapidity of the social and economic changes in the world to which the people of that time were trying to adjust themselves, with the resulting strains and cracks in the social structure. "Unless," he said, "a breakdown occurs in the social order—which is always possible—leading probably to a very much lower scale of living, it seems to me inevitable that the *tempo* of scientific discovery and advance will be more in the biological sciences than in the physical sciences, but nothing can prevent the advance so long as the social order remains. It is to be hoped for the benefit of our grandchildren that the world might not move as fast as it has done in our own lifetime.

"The greater part of our industries are only half-awake, indeed some of them might be described as still asleep, in the matter of research. They must all realize, especially in this era of economic nationalism, which shows no signs of diminution, but rather an increase, that there is going to be a very keen and severe struggle for trade throughout the world. I think that there is not the least doubt that the nation that will have the advantage is the nation with a well-balanced scientific background.

"Not only am I speaking of the background of research institutions and large organizations like the Imperial Chemical Industries and others, but we must also get a scientifically-minded industry. Those who manage the industry, even if they are not scientific experts, at any rate must be scientifically minded. The Department of Scientific and Industrial Research is doing its best to promote this ideal, and this year the Government has given extra funds to help in trying to increase as rapidly as they can the

efficiency and size of those research organizations which have to deal with the scattered industries, often small units, that cannot deal with research individually."

Rutherford then drew attention to the fact that the people of the United States were more scientifically minded than ourselves, and that unless we made haste we would be left behind. Rutherford pointed out that a purely scientific discovery can in time prove to be of great industrial value as exampled by the discovery of inert rare gas, argon, by Lord Rayleigh and Ramsay at the close of the nineteenth century, which remained for many years as a scientific curiosity. But in 1934, 30,000 cubic metres of argon were being used annually in Europe in the production of highly efficient gas-filled electric lamps, of which some 45 millions were made every year. He also referred to the great use made of neon, another inert gas, which has almost revolutionized the electric advertising sign.

On 10 December 1935 Rutherford opened the new L.M.S. Railway Research Laboratory at Derby, the party with which he travelled setting out from St. Pancras in a special train. Before the journey started, however, a little ceremony was performed. One of his grand-nephews, Pat Rutherford, was introduced to the guests by Sir Josiah Stamp and was then lifted on to the running plate of the engine, where, on his pulling a cord, a purple cloth fell back to reveal the engine's name-plate. At the same time Pat called out, "I name this engine 'Lord Rutherford of Nelson.'" In this way the L.M.S. Railway conferred upon Lord Rutherford the most unusual distinction of having an engine named after him while he was living.

In his speech at the opening of the laboratory Rutherford said:

"To obtain," he said, "the best results from a laboratory such as this one, it is essential to develop mutual respect and understanding between the scientific and the practical man. I hope that the officers and staff of the railway will take the greatest interest in this new laboratory and utilize its services to help solve their problems."

Reporting on his visit to the Electrical Research Laboratories of Callenders Cable Co. Ltd., a correspondent in *The Times* newspaper said: 'The impression gained during a

visit of a few hours to these laboratories is that there is a very real understanding of the value of comprehensive research to the manufacturer and that money spent on the most up-to-date equipment is a very good investment, assured of adequate return.' These words demonstrate the success being attained as a result of Rutherford's campaign on behalf of industrial research.

In an appeal in 1936 to the British Refractories Research Association for increased support for it and for the extension of its activities to research on building bricks, tiles, and other clay materials, we have a good example of the energetic way in which Rutherford encouraged further and better progress in the work of backward associations.

"The Council," he said, "was somewhat exercised some eighteen months ago when we reviewed the position generally to find on what an inadequate basis some of the Research Associations were operating. We came to the conclusion that a big effort must be made to place the organization on a firmer and more stable financial footing and we succeeded in persuading the Government that it should play its part in the forward movement. The impetus thereby has been given an immediate and effective response from practically all the industries with which we are concerned, industries representing something like half the export trade of this country. One or two of the associations have not yet made proposals, and the one I have in mind particularly is the British Refractories Research Association. Some increases in recent years of the resources of this association have been recorded, but even so, the subscription income is under £5000 per annum, and the total income from all sources is only just over £8000. The minimum income ought not to be less than £20,000 a year.

"I am convinced that British industry . . . will need not only to use science more and more, but also to use the co-operative research associations to the full. I confidently look forward to the time when the research associations in this country will be the nerve centre of the industries they serve."

It was, perhaps, inevitable that the older industries should be the most reluctant to make use of scientific research, and Rutherford spent some time in encouraging and persuading them to overcome the conservatism resulting from their

long existence. He found that many manufacturers were of the opinion that because their craft was centuries old it could not be improved, while the old-established firms were loath to collaborate with any firm which might in any way be considered to be working in rivalry.

Individuality of this sort also made its appearance in newer industries, notably the motor industry.

At the time the leading firms of motor car manufacturers had their own individual laboratories, in which they engaged on research and inventive design for their own private benefit. Rutherford pointed out that there were certain problems to be attacked the solution of which would be of benefit to the motor industry as a whole. Under the ægis of the Institute of Automobile Engineers an independent laboratory was built for the purpose of giving valuable results to the entire industry.

Such institutions required money and took time to bring into being, and Rutherford said that during 1935 his Council had been reviewing the situation and had come to definite conclusions.

" The first is," he said, " that this experimental movement of co-operative research has achieved a large measure of success under great difficulties. These are twofold. There is first the individualistic outlook of the British manufacturer who looks somewhat askance at the idea of co-operation. This attitude is perhaps more marked in the older industries than yours, but still a characteristic of the British manufacturer generally. The other grave disability under which the movement suffers is finance.

" The Council are of the opinion that unless research associations have over £10,000 a year to spend on its programme it is not worth while ; and, further, that sums considerably in excess of this amount are needed for such an industry as yours. . . .

" In order to give a practical expression of its views the Department has decided, on the advice of the Council, to offer to the co-operative research associations a block grant of £5000 a year so soon as your industrial income tops £10,000, and it is prepared to find another £5000 if your industry provided another £5000."

When he opened the extensions of the Shirley Institute

of the Cotton Manufacturers' Association he called attention to the necessity of research associations devoting their funds not only to the scientific needs of the present and the near future, but of looking into the distant future. "I am interested," he said, "to see and know that the new developments of the Shirley Institute will be used very largely for the long-range or fundamental researches that it is hoped will have influence on the industry in the future."

In dealing with the question as to why the Government Industrial Research Department did not take over the finance of the whole work of such an association or institution, he said: "The policy of the Department is to say that if an industrial research organization is to be successful, it must be a service rendered by the industry for the industry. The function of the Government Research Department therefore is that of offering a reasonable size carrot as a contribution towards sustenance.

"The Government, last year, provided about £20,000 towards the Shirley Institute. If you are prepared to go forward a little faster, we are prepared, up to a period of, say, 1939, to give you another £20,000 a year, or a little over £40,000 in all, provided you in your turn have shown your interest in the Association by contributing an equal amount. That offer is open and holds until the year 1939, and I hope you will have qualified for a full grant long before then."

In this way Rutherford dealt with many of the research associations, challenging them always to go one better than they were. On the whole subject of industrial research he brought to bear his wisdom, his quick perception, and his extraordinarily developed gifts of lucidity and emphasis on essentials. He also brought to bear that uncanny way of his of seeing into the future, or, as was once said, "of seeing the answer to the sum without going through the dull mechanic process of working out the algebra," and in this matter, as in many others, it is more than likely that he spoke with a wise prevision.

Among the difficulties with which scientific men who take an interest in industry are faced to-day is educating various authorities in scientific ideals.

The inefficiency of many of our local governments and

certain departments of State is appalling and their attitude towards experts in many cases, if it were not for its disastrous effect, would be amusing. Rutherford did not think that such authorities would ever be educated in that respect. At a joint meeting of the British Science Guild and the British Association he once said that the idea that they could influence more than a limited number of persons was a mistake. By popular addresses it was only possible to impart a smattering of knowledge. The best thing to do was to interest the younger people in scientific matters, so that as they grew older their knowledge and keenness would increase.

In December 1936 Rutherford opened that excellent exhibition of Electrical Illumination at the Science Museum, South Kensington. His remarks formed a very appropriate survey of the effect of scientific industrial research in one branch of industry. He said: "During the past ten years there have been remarkable advances in illumination, which, emanating as they have from pure science research undertaken in the industrial laboratories, illustrate admirably the close relationship between science and industry. . . . Eighty candle hours ten years ago cost the same as three hundred candle hours to-day, and this improvement happily comes at a time when it is really wanted in the cause of road safety. . . . Some twenty-five thousand hot cathode discharge lamps now illuminate one thousand miles of road in Great Britain alone. . . . I hope to live to see the time when we shall obtain light without filaments or electrodes, simply by the conversion of invisible radiation."

How much was due to Rutherford during his period of office as Chairman of the Advisory Council we may never know. His spirit pervaded his surroundings and 'leavened' the work of his associates. He was the driving force, and as such Rutherford was unique. The amount of work he could do and induce others to do by his personality was immense.

The woollen firms have been, and are, very loath to form a completely representative research association. Even at the time of writing (1939) they have not a sufficiently representative proportion of manufacturers banded together to enable a Bill similar to the Rubber Industries Bill to be introduced into Parliament.

Speaking to them in April 1937 Rutherford drew attention

to the fact that the Dominion wool-growing countries realized that much work still remained to be done to improve the breed of sheep. They were prepared to spend money.

"The general method," he said, "of research associations set up in this country is unique. It suits the Englishman's individualistic heart. The Government has acceded to the request that more money should be spent on research, and the grant of £200,000 has enabled the various research authorities to increase greatly their scale of work. Unfortunately the Wool Industries Association has not so far been able to take advantage of that grant to extend its scope, but, failing support for a proposal for a statutory levy on the industry, other steps are being taken to get the industry to work together."

In order to have research laboratories, one must have workers to fill them, and the only way to obtain workers is to train them for the purpose. In the address Rutherford wrote and intended to deliver to the Indian Science Congress Association in 1938, he said: "In this present scientific age efforts are everywhere being made to develop national resources to the utmost, to improve industrial processes and to increase our knowledge in pure science. It is to the universities and technical institutions that we must look for men to carry out this work. The universities must be able, not only to give instructions, but also to select those who are to be trained in the methods of research. From the latter we may expect to obtain future leaders of research on whom the prosperity of the country will largely depend.

". . . The utilization of science implies, moreover, a planned scheme of research . . . centralized organization of research is the only way of avoiding waste of money and effort. The detailed planning of research must be in the hands of those with the necessary specialized knowledge and they must be able to act without suspicion of political or (in India) racial influence."

On looking through the annual reports of the Department of Industrial and Scientific Research during the years that Rutherford was Chairman of the Advisory Committee one can see how greatly the work increased from year to year. From the report for 1937, which he shaped for publication just before his last illness, and was in fact his last act in official

capacity, some idea of the vastness of the task lying before the Council can be gained and realization of the great influence exerted by research associations of to-day acquired.

This chapter cannot be more suitably ended than by quoting the words of Sir Frank Smith in *The Times* newspaper, written two days after Rutherford's death and telling of the private service he rendered to his country during those seven years when he was Chairman of the Advisory Council.

'Those who are familiar with its work know that the Advisory Council plays a great part in the Department; but only those who know its activities from inside can realize fully how deep and how wide was the contribution which Lord Rutherford made to its policy, alike in its broadest outlines and its smallest details. Lord Rutherford was unsparing in the time and consideration which he gave to all the questions that came before the Council. That he found it possible to devote so much energy and thought to the task he had undertaken was due to a profound conviction that in the effective application of science in industry lies the future of this country. The world of science will pay homage to his outstanding achievements in pure research and to his inspiring influence on the distinguished band of investigators he gathered around him. It is more significant for this reason that, whenever opportunity offered, one of the most original minds in the history of physics should have found an equal interest in pressing the claims of science to be allowed to serve industry, no less in the day-to-day routine of manufacturing process than in those major advances of knowledge which, in effect, develop new industries out of old ones. The debt which the nation owes to Lord Rutherford for his work as chairman of our Council should take its due place in our grateful memories of the man.'

CHAPTER XXII

WANDERING SCHOLARS

THE month of April 1933, which brought Adolf Hitler into power as Chancellor of Germany, saw the beginning of grave disorganization in the scientific world as well as the political.

It was a 'new communism,' imposed by force, but accepted widely, if not universally, with an enthusiasm which appears to have crossed the bounds of fanaticism, bidding fair 'to reduce the whole of Germany as nearly as is humanly possible to one common denominator and to block every angle of vision but one in her political and intellectual kingdoms alike.'[1]

On expelling from her public life those whom she regarded as unfit on religious, racial, or political grounds, Germany robbed herself of the services of many of her greatest intellects, for great numbers of the best brains in Germany were situated in Jewish bodies or were opposed to the Nazi form of government.

In 1933 nearly a thousand men prominent in the arts and sciences, who had raised and maintained the high intellectual level of the German universities, were deprived of the opportunity of carrying on their work. While balanced judgment should allow Germany to know her own business best, it is impossible not to feel that Germany struck a foolish blow at herself by ridding the country of those who had placed her industries, her intellectual status, and the service of science in the front rank among the great nations, and committed a blunder at a moment when she needed every resource of science to be pressed into use in the aim for self-support and against fierce competition.

This abrupt dismissal of university teachers raised an

[1] *Nature*, 1933.

acute problem in the rest of the world as to what could be done to help them. Within a few weeks of assumption of power by the National-Socialists in 1933, nearly a thousand men of learning found that they had become virtual exiles in so far as they were concerned with their work. About half of those displaced were retired from their spheres of influence and granted pensions, and thus prevented from prosecution of their work. The remainder were exiled or exiled themselves from Germany.

As is usual in such cases, Great Britain took an early and decisive step in organizing on a comprehensive scale a scheme of assistance for these scholars. The universities helped certain individuals, but their powers in this direction were strictly limited. The men of first rank and international renown found positions open for them in England and America, but even then there were many faced with penury.

It was obviously more difficult to deal with and absorb those of less repute. A very few were absorbed, but the financing and placing of the refugees could not be legitimately allowed to interfere with the ordinary competition for appointments. It was neither fair nor practicable to have 'a most favoured nation' clause for the displaced German teachers and research workers.

In view of these difficulties and restrictions the Academic Assistance Council was organized, a provisional Council being set up in May, 1933, which issued a statement of the aims and methods to be followed by the Council if it received the necessary support.

This body was formed to co-operate with similar bodies in other countries in collecting funds to provide maintenance for the scientific refugees and placing them in universities and institutions where they would be able to carry on with their normal work as far as possible. The Council was to act in a double capacity; first, as a centre of information and as an organization for putting the teachers into touch with institutions; secondly, to seek funds to be used primarily, though not exclusively, in providing maintenance for displaced teachers.

The situation that had been created was described in a leading article in *Nature*:

'While Germany may claim as a matter of domestic

concern to lay down such regulations for appointments in and admission to her academic institutions as she may deem fit . . . it is a matter of concern to the whole scientific world that a number of workers, now considerable, be they Jews or members of any religious or political group whatsoever, are deprived of the opportunities they have hitherto employed in adding to the sum total of scientific knowledge —researches by which ultimately the whole world has benefited—irrespective of nationality. It requires no special pleading to show that while Germany persists in her present attitude . . . it is of advantage to the scientific world and an international obligation to ensure that everything possible is done to receive the continued benefit to science of these displaced workers.'

As it appeared to the Council that intolerance might raise its head in other countries, it proposed to utilize the funds entrusted to it for the purpose of assisting scientific people from any country who, on grounds of religion or political opinion or race, might be unable to carry on with their work in their own countries. Amongst those who were dismissed and needed assistance were :

Professor Max Born, Physicist. Now at Edinburgh University.

Professor Franz Simon, Physicist. Now at Oxford University.

Professor James Franck, Physicist. Nobel Prize winner, Johns Hopkins University, Baltimore.

Professor Fritz Haber, Chemist. Nobel Prize Winner. Deceased.

Professor Albert Einstein, Mathematician. Nobel Prize Winner, now at Institute for Advanced Study, Princeton, N.J.

Professor Moritz J. Bonn, Economist. London School of Economics.

Professor Karl Barth, Theologist. Basle University.

Professor Karl Brandt, Economist, Stanford University, U.S.A.

Professor Ernst Cassirer, Philosopher. Goteborg, Sweden.

Professor Friedrich Dessauer, Radiologist. Fribourg University, Switzerland.

Professor Casimir Fajans, Physical Chemist. Michigan University, Ann Arbor.

Professor Eduard Fraenkel, Classical Languages. Regius Professor, Oxford University.

Professor Herbert Freundlich, Physical Chemist. Now at University of Minnesota, St. Paul, Minn.

Professor Erwin Finlay Freundlich, Astronomer. Professor and Director Observatory, Prague University.

Professor James Goldschmidt, Criminal and Civil Law. Formerly Professor Berlin University. Unplaced.

Professor Fritz Schulz, Roman Law. Formerly Berlin University. Unplaced.

Professor Martin Wolff, International and Comparative Law. Formerly Berlin University. Oxford University.

Professor Paul Hermberg, Economics and Statistics. Bogota University, Colombia.

Professor Julius Hirsch, Professor of Scientific Management. Graduate School of Commerce, Copenhagen.

Professor Karl Mannheim, Sociologist. London School of Economics.

The Council also emphasized that its formation implied no reflection on political issues in foreign countries, but was solely concerned with relieving suffering, preventing waste of valuable talent, and defending learning.

The great difficulty was the fact that at the time England herself was recovering from the financial situation of 1931, while on the Continent the democratic countries were still in grave financial trouble. In addition, the academic market was already overcrowded. The Council therefore proposed to devote part of its funds as maintenance grants to enable research workers to carry on until a position was available within a definite period of two years. At the end of the period it was hoped that a process of adjustment would have worked itself out.

The secretaries to the provisional Council were Sir William Beveridge and Professor C. S. Gibson, and offices were placed at the Council's disposal by the Royal Society. A long list of eminent people in the field of learning were subscribed to the appeal :

Sir Frederick Gowland Hopkins (then President of Royal Society).

Lord Buckmaster.

Lord Cecil.

Lord Crawford.
Sir William Bragg.
Dr. Allen Mawer.
Dr. Gilbert Murray.
Lord Eustace Percy.
Sir Frederic Kenyon.
H. A. L. Fisher.
Sir George F. Hill (Director of the British Museum).
J. M. Keynes.
Lord Lytton.
Sir William Pope.
Sir Josiah Stamp (now Lord Stamp).
Sir J. J. Thomson.
Sir Michael Sadler.
Sir Charles Sherrington.
Professor Eliot Smith.
Lord Rutherford.

The response to the appeal was adequate enough to enable the Council to be formed constructively, and in this way began one of the greatest interests of Lord Rutherford. He was elected President of the Academic Assistance Council and Chairman of its Executive Committee and became an extremely active force in its workings. It was the only public body of its kind in which he took any interest.

Under Rutherford's Chairmanship the Council progressed at a considerable speed, considering its difficulties. One of the greatest was the fact that men of learning cannot be placed in positions outside their own fields, it being extremely wasteful of talent to do so, while the requisite placing had to be done without prejudicing existing claims and upsetting existing conditions.

Within six months about 1000 displaced scientific workers were on the books of the Academic Assistance Council. Of these 132 had been given maintenance grants of £250 per annum for married persons and £182 for unmarried persons. Inquiries all over the world had been made for permanent or semi-permanent posts.

About a year after the institution of the Council Rutherford reported its progress in an article in *The Times* newspaper.

" In the conviction that the universities form a kingdom

of their own," he said, " whose intellectual autonomy must be preserved, the A.A.C. was formed to defend academic freedom." He pointed out the loss to science which had occurred through lack of organized assistance during previous political revolutions since the Great War, revolutions which had, in his words, " created a large body of wandering scholars ; many, for instance, among the Russian and Italian *émigrés* have unfortunately . . . lost the means of continuing their scientific careers." That band was now swollen by the lack, among other things, of what Rutherford called " that strangest qualification of life— ' Aryan Origin '."

He indicated the difficulties to be faced, pointing out that they did not exist even in the Middle Ages when ' communities of learners ' were less hampered by various restrictions of endowments and the like, so that universities could move with the wandering scholars.

During the past year many things had taken place. The universities of Great Britain had given their facilities to the unfortunate, while the staff of the London School of Economics had placed a voluntary tax on their own salaries to provide a fund of their own which worked in conjunction with the A.A.C. In that period £13,000 was obtained, including a grant of £2500 from the Central British Fund for German Jewry. Still the Council lacked funds and could not do as much effective work as Rutherford would have liked.

It is of marked interest that through enabling workers to continue their work in British universities and other institutions, several notable discoveries were made by the exiles in this country, while the English and Germans were found to collaborate excellently.

In the latter part of the year the central information bureau showed its importance. More than thirty[1] posts were obtained on the reorganization of the University of Istanbul, and the ' University in Exile ' was formed in New York ; openings, through reorganization, appeared in Russia, Persia, and Brazil, with, in some cases, the possibility of group settlement.

" I believe," said Rutherford, " that as the academic

[1] See footnote, p. 256.

distinction and scientific qualifications of the wandering scholars become known, the problem will solve itself," but unfortunately this very logical suggestion was not borne out by events.

In October 1933 Rutherford was chairman of a great gathering of the various relief associations, including the Quakers, at the Albert Hall. The meeting was to raise funds for the relief of refugee students, teachers, members of the professional classes of any country which debarred them from carrying on their work through no fault of their own. Rutherford said: "Our contributions in this emergency must be mainly a financial one, combined with the provision of a temporary refuge in our universities and other learned institutions for some of the distinguished scholars, scientists, and others, who find themselves faced with destitution and complete collapse of their academic careers."

In May 1934 the number of university teachers displaced had reached 1292[1] of which only 309 had found even temporary places, while 178 of these had found their academic refuge in Great Britain.

In 1935 a blow fell. Owing to world conditions some of the Academic Committees on the Continent were unable to continue their work. The Council had obtained another block grant from the Central British Fund for German Jewry and numerous contributions from various parts of the world of learning, but though it had, in June 1935, a sum of £6721 for its work during the coming twelve months, the new conditions were making a great demand on its resources. Rutherford, therefore, issued an appeal for funds.

Rutherford was taking as a policy for the A.A.C. one which was completely free from political, racial, or other controversial policy that might endanger the individuality of the A.A.C. It was simply a body whose only policy was the relief of learning from domination by extraneous influences.

The Council could not accomplish all that it had wished to do by November 1934, but it had placed 200 people

[1] The reader should bear in mind that the figures given are for the total number of academic refugees helped by the A.A.C. in conjunction with similar societies in other countries, particularly the U.S.A.

permanently and had provided temporary facilities for 325, or, as Rutherford said, " at least two-thirds of the whole number who were justified in looking to continue their scientific work." Seventy-one people received emergency grants while they were looking for posts. Altogether it was a creditable record for eighteen months' work by an organization formed at a time when Great Britain and the United States were in a state of economic depression never before paralleled.

Now that Rutherford knew the size and nature of his problem, his Council proposed to form a trust for the creation of a number of research fellowships for exiled scholars of special distinction, to be awarded irrespective of nationality. America gave a ready response to the suggestion by announcing the prospect of a contribution which would finance 36 fellowships, tenable for three years in any university in the British Empire. Subsequent events in American economics, amongst other causes, were responsible for the non-fulfilment of this promise. The most that happened was that the Carnegie Corporation then and since made grants to universities in the Dominions, not fellowships to individuals, enabling them to appoint German refugee scholars to their staffs on condition the universities absorbed or re-established them after two years. The Council was gradually reaching a pan-national basis which, when attained, would confer upon it a unique position as permanent international rallying-point for the defence of academic freedom.

In March 1935 the High Commissioner for Refugees (Jewish and others) from Germany published a pamphlet entitled ' A Crisis in the University World.' It described the work done to assist the displaced university teachers from Germany.

Rutherford reviewed this pamphlet in an article in *The Times* newspaper.

' It is interesting,' he wrote, ' to see that . . . almost all the displaced in exile have been maintained within the university sphere, a magnificent demonstration of the support of the principle of the preservation of learning.'

The pamphlet gave several statistics. The Academic Councils of Europe and the U.S.A. had collected nearly

£200,000 in two years; universities had in most cases given the hospitality of their libraries and laboratories, since in most cases they were restricted from giving financial assistance themselves; the funds had been contributed 'without distinction of race or creed.' "It is one of the most satisfying aspects of the work of the A.A.C. in this country," said Rutherford, "that substantial support should have been received from both Jewish and non-Jewish sources." The Jewish organizations provided £10,750 of the £28,000 subscribed, the rest coming from small non-Jewish donations, mainly those of university teachers and graduates.

Again Rutherford stressed the non-sectarian aspect of the Council. "Neither in fact nor implication is the problem a Jewish one alone," he said, "and it has been approached and must continue to be approached as one involving principles demanding the support of all who believe in the freedom and security of learning."

Looking towards the future, he said: "In many ways the future work will be harder than the past. . . . The international task is to transfer the 300 temporarily placed scholars into more permanent positions and to maintain them during the process in positions where they may continue their studies."

Many of the scholars were engaged in subjects such as philosophy or the classics, in which there was a very limited field of absorption. Many of the unplaced were young men and women without any international reputation, "yet," said Rutherford, "it is the younger age group, because of its potential importance in future research, which most deserves and needs extraordinary assistance in re-establishment."

Describing the future programme of the Council, Rutherford said: "It wishes to continue its international information service and investigations for openings; to continue a system of grants-in-aid to about seventy displaced scholars for no more than two years; to subsidize occasional short lecture-courses in Great Britain for those of the displaced scholars who are able to support themselves in Germany, but have otherwise no opportunity of announcing the results of their research or maintaining contact with their colleagues; and to create twenty special research

fellowships awarded in the first place for three years, which will enable us to retain for this country the services of some of the most distinguished or promising of our guests. This is a manageable task. . . ."

The trouble was still finance. The pamphlet stated: 'The solution of the problem is known; every factor for success is present—plans, experience, international co-ordination, university co-operation—except for the one vital factor of finance. The financial requirements are small in relation to the importance of the work. . . .'

Rutherford ended his review by saying: "I should like to express a personal hope. There has been accumulated a body of highly technical experience in the transferring of scholars unable to continue their work in their own countries to other countries which will welcome their services. The function of the discriminant distribution of talent which is unemployed for social, religious, or political reasons may prove increasingly valuable in the international world of scholarship as national prejudices harden and the privilege of liberty is restricted. It would be appropriate if the experience gained in the present crisis could be preserved by means of a more permanent international organization. Contemporary conditions contain real dangers for free scholarship and it is of great importance to consider the best means of defence for our present liberties.

"I feel after reading this pamphlet that the immediate opportunity exists for the creation of a service—permanent academic assistance fund which might well prove to be of great historic importance in the development of our universities."

This hope of Rutherford's was fulfilled.

In March 1935 the Academic Assistance Council decided to appoint a permanent successor—a Society for the Protection of Science and Learning.

It was incorporated as a company limited by guarantee to carry on the work of the Council. Its project was to build up a fund for research fellowships tenable in Great Britain and other countries; it was to be administered under the auspices of the Archbishop of Canterbury, the President of the Royal Society, the President of the British Academy, Lord Horder, Mr. R. H. Brand, and Lord Rutherford.

By this time 1300 displaced university teachers, research workers, and scholars had been assisted, as well as refugees from Russia, Portugal, and other countries. Announcing the progress of the A.A.C. up to its reorganization, Rutherford mentioned that 363 of the 700 displaced people had been permanently placed, while 324 had been found temporary positions. £46,000 had been received in donations and a place-finding organization of 'increasing usefulness' had been built up.

A significant pronouncement by Rutherford was as follows:

"The Council hoped that its work might be required only for a temporary period, but it is now convinced that there is the need for a permanent body to assist scholars who are victims of religious and political persecutions. The devastation of the German universities still continues, not only university teachers of Jewish descent but many others who are regarded as 'politically unreliable' are being prevented from making their contributions to the common cause of scholarship."

The Society for the Protection of Science and Learning is now a permanent body, built on a subscription basis. It does not interfere with any other relief body, rather it helps them, for its work of looking after displaced scholars lessens the burdens placed on other societies.

At the end of 1936, 530 of the 'wandering scholars' had been placed in permanent positions, 330 in semi-permanent posts, and the total number of exiles assisted was 1600.

Scientists all over the world know now that, thanks to Rutherford's energy and foresight, there is a refuge for them through the mediation of this British organization so that they can be sure of protection from any persecution or other weapon of the enemies of academic freedom. Thus, when Austria was recently acquired by Germany, some 600 university teachers were displaced, and Rutherford's work will help them to live and to carry on without loss of any of their powers.

Dr. Demuth, chairman of Notgemeinschaft deutscher Wissenschaftler im Ausland, ends his appreciation of the services of Rutherford with the words: 'It is with deepest respect and gratitude that the name of Lord Rutherford

will ever be recalled by those German scholars who may not remain in the Germany of to-day, and especially by the many who through the efforts of the organization of which he was so active a president, have found a new place in the world of learning.'

If Rutherford had made no other contributions to science, this work alone would have made him internationally famous in the realms of learning and would have ensured perpetual memory of his name. This permanent memorial which he has left behind is of a kind he himself would have desired.

CHAPTER XXIII

OVER THE HEDGE

THE McGill, Manchester, and Cavendish Laboratories are the fields of Rutherford's scientific adventures. Over their hedges is the world in general. Unlike certain scientists, Rutherford often looked over the hedge and on occasions jumped over to take part in worldly activities.

He never lost touch with the progress made in wireless. His first scientific paper was on this subject, while, in Canada, in 1902 he made the first wireless communication between the station and the receiver in a moving train. That was his second contribution. His continued interest in the subject is made apparent by the fact that his presidential address to the Royal Society in December 1926 was almost entirely devoted to radio.

He referred to many striking advances that had been made in radio communications and to the new avenues of research on the electrical state of the atmosphere which were being opened up by the study of the mode of propagating wireless waves over the earth, and he said that among the many developments during the past thirty years none had left a deeper impression both on the lay and scientific mind than the remarkable growth of wireless. . . . He pointed out the advance illustrated in a vivid way the value of close co-operation between pure and applied science for making rapid progress.

He sketched the history of wireless from the first chapter of Clerk Maxwell's paper 'A Dynamical Theory of the Electro-Magnetic Field,' which led to the researches of Hertz, the pioneer work of Sir Oliver Lodge, and the late Senator Marconi. Later progress, he said, had been largely influenced by the scientific discovery by Professor J. A. Fleming of the wireless valve.

To-day the year 1926 in wireless seems as remote as the Middle Ages, but it saw the real beginning of what we are familiar with now. He referred to ' the noteworthy development . . . the new Post Office station at Rugby . . . opened for the transmission of messages to ships in all quarters of the globe. . . . It was in many cases unique. It is the only high-power electron-tube station in the world and contains many novel features. . . . The frequency of the continuous waves emitted . . . is controlled with great accuracy by a vibrating tuning-fork and the numerous high-power electron tubes in parallel are used to magnify 500 million times the energy of one of the harmonics of a small triode valve operating the tuning-fork.'

In May 1930 Rutherford from his home to the Royal Society of Canada at their General Meeting in Montreal. His speech was broadcast by wireless throughout Canada.

When the Kelvin Medal was presented to Marconi, Rutherford recalled that he had devised a simple magnetic detector in 1896, and said that he was glad that Marconi had been able to develop and transform it into a reliable metrical detector.

When he opened the Halley-Stewart Laboratory at Hampstead, Rutherford paid great tribute to one of his former students, Professor Appleton, and it indicates the Rutherfordian influence on Appleton's early work.

" In a sense," Rutherford said, " I take an almost parental interest in this new departure, for Professor Appleton opened up the new methods of attack on the constitution of the upper atmosphere when he was working in the Cavendish Laboratory in Cambridge in 1924. . . . In 1924, Appleton brought before me proposals for experiments to make a direct test of the existence and height of such conducting layers (the Heavyside-Kennelly Layer). Assisted by a group of research students prominent among whom were Mr. Radcliffe and Dr. Bennet from New Zealand, experiments were carried out between Oxford and Cambridge. They were immediately successful . . . and were promptly recognized by the Radio Board of the Department of Scientific and Industrial Research."

The researches made rapid progress and a second ionized reflecting layer was disclosed ' high up in the atmosphere,

still richer in ionization. . . . In honour of its discoverer it was known as the Appleton layer. . . .

Rutherford ended his speech by saying : " I am confident that this laboratory will soon be recognized as an important centre for studying the electrical conditions in the upper atmosphere. This is a problem of fascinating interest and of great practical importance, for on it depends the more complete understanding of the propagation of radio signals and broadcasting over the surface of the earth."

In June 1933 Rutherford, as the representative of science in Great Britain, delivered an address from England by wireless to the Fifth Pacific Science Congress at Vancouver.

Apart from the scientific side Rutherford was actively concerned with broadcasting in the British Empire. He was one of the original members of the British Broadcasting Advisory Committee appointed in 1925, and with his usual tact and by the force of his personality he was able to give much help to the Committee struggling with problems in the early days of broadcasting. As a New Zealander, he was particularly interested in doing all he could to further Empire Broadcasting.

Replying to the toast of ' Science ' at the Royal Academy Banquet in 1932 he made some succinct remarks on the relations between the State and Science. First, he referred to ' the certain bond of sympathy and understanding between the artists and scientific men,' mentioning the thirty years work on colour by the late Professor Wilhelm Ostwald, the founder of physical chemistry.

Continuing, he said : " The importance of science to the modern State is increasingly recognized in these days and there never has been a time when science was in a more flourishing state, judged either by the extension of our knowledge of the workings of Nature, or by its application to industrial problems. It is a time of intense intellectual activity, rich in the development of new ideas and methods. For nearly three centuries this country has produced its full quota of great pioneers both in pure and applied science, and it still continues to do so.

" Quite recently there has been much interest taken by the cultivated public in the metaphysical aspects of science,

especially in those of theoretical physics. Some of our publicists have boldly claimed that the old ideas which have served science so well in the past must be abandoned for an ideal world where the law of casualty fails, and the principle of uncertainty, invaluable in its proper domain of atomic physics, is pushed to extremes.

"The great array of scientists, in its march into the unknown, discusses with interest and sometimes amusement these fine-spun disputations of what is reality and what is truth. But it still goes marching on calling out to the metaphysician: 'There are more things in heaven and earth than are dreamt of in your philosophy.'

"Even in these times of financial depression there is every reason to foster the development of science and the arts. Men do not live by bread alone, and they may be sure that the position of our Empire in the world of to-morrow, if not to-day, will be estimated not so much by its material wealth as by its contributions to the world of arts and sciences."

Rutherford had a few words to say on journalists at a dinner in 1934. He said:

"The profession of journalism is as important as any other profession in this country. In these difficult days it is of the highest importance that every profession should be organized, to be able to speak for itself strongly when the occasion arises. We have seen in another country the whole of certain professions put under orders at a moment's notice. I cannot for one moment imagine the Press in this country sitting down under that treatment if it has a proper organization to speak out."

Then he added a few words directed at those pessimists who hold scientific development responsible for the horrors of modern warfare.

"Science, whether for good or ill—I am sure it is for the good—is transforming the material world and will exert an ever-increasing influence not only on the material and industrial situation, but also on mankind in general." Following this he stressed the importance of a great need in modern journals. A need that is gradually being supplied by certain newspapers.

"What is required," he said, "is a trained journalist profession that can report accurately and interpret with

wisdom the workings of the scientific mind. The average scientific man, especially the discoverer, is the least qualified to put his idea properly before the public. It is encouraging to think that the Press is devoting more attention to scientific articles. The young generation are being brought up on wireless and know the technical terms in that science, and boys and girls are interested in engineering, in motor cars and flying machines. Therefore there is a large public growing up which can absorb scientific talks even though such talks are not in baby language."

In dealing with Empire problems he once warned a gathering of New Zealand graduates and undergraduates in England that there was a real danger to New Zealand because they came to England and stayed to compete with Englishmen for jobs. While that might be an advantage to England, he said, it was a disadvantage to the Dominion, and his warning applies to-day. Certain countries in the Empire are finding themselves short of doctors because of the number that stay in England to practise.

In 1935 Professor Kapitza, who worked with Rutherford at Cambridge, was detained in Russia, an event which 'came as a severe shock to the scientific world, and quite apart from the general problem of the liberty of the individual has raised some questions of vital importance with regard to international scientific relations.'

For twelve years he was financed by British sources, the Mond Laboratory had been constructed by the Royal Society for him, and he held their Messel professorship. Everything was ready in 1934 for Kapitza to start certain important researches on the study of the properties of matter at or near the temperature of absolute zero when under the influence of intense magnetic fields. That summer he went on his usual holiday to Russia and was not allowed to come back.

The handling of this rather delicate situation could not have been placed in better hands than those of Rutherford. The capable and diplomatic way he handled it is one of the finest examples of his vision and shrewd judgment in a sudden crisis. But all the same the loss of Kapitza was a severe blow to the work in the Cavendish and a great disappointment to Rutherford.

Rutherford said in a letter to *The Times*: 'While no one disputes that the Soviet authorities have a legal claim upon Kapitza's services, their sudden action in commandeering them without previous warning has profoundly disturbed the University and scientific world. He was not even allowed to return to this country to discuss with the University authorities and the Royal Society arrangements for carrying on the work of the laboratory of which he was director. It requires no imagination to realize how painful Kapitza's position is, for he was on the eve of completing the experiments in Cambridge, for which he had so long prepared. . . . Science is international and every scientist hopes that it will long remain so, and the facilities granted to Kapitza in this country are a good example of the facts . . . but the personal factor is a vital one in creative work. It is inevitable that Professor Kapitza has been greatly disturbed by this sudden frustration of his work and by the conflict of loyalties involved in the action of the Soviet Government, and reports from Russia make it clear that his health has been seriously impaired by anxiety and disappointment. Men of scientific originality and imagination like Professor Kapitza require an atmosphere of complete mental tranquillity in which to do their creative work. It would be a great misfortune in the interests of science in the world at large if, through lack of understanding or sympathy, conditions should arise which would inhibit Kapitza from giving his best to the world. . . .'

Rutherford expressed the hope that the Soviet Government would do all it could to enable Kapitza to choose his own environment. He said: 'It would be a tragedy if these gifts were rendered sterile by failure to grasp the psychological situation.'

Fortunately the Soviet Government did all it could to enable Kapitza to carry on his work in Russia, and he was eventually appointed the Director of the Institute of Physical Problems, which was specially constructed for him in the grounds of the Academy of Science in Moscow.

In November 1935 Rutherford was appointed Director of the Royal Society Mond Laboratory, where he had been acting-director since Dr. Kapitza's unfortunate holiday. He was now a very busy man, being Chairman of the Advisory Council of the Department of Scientific and Industrial

Research, Cavendish Professor of Physics, Director of the Mond Laboratory, Professor of Natural Philosophy at the Royal Institution, and President of the Academic Assistance Council; in addition he filled many honorary and advisory posts in connection with various bodies. He did not allow these multifarious duties to interfere with his direction and supervision of the Cavendish. He was rewarded by knowing that the Cavendish 'trade mark' meant the finest possible goods.

In a letter written by him in conjunction with Sir William Pope to *The Times* in 1920 the admission of women to Cambridge was defended. Certain passages are worth quoting. Two prominent scientists attack the diehards and enjoy themselves.

'The arguments advanced by the opponents . . . share the trivial character of those which have been advanced without ultimate effect whenever it has been proposed to admit women to an established corporation or institution.' Rebutting the overcrowded laboratories argument, they said: 'The two laboratories over which we have the honour respectively to preside are the most frequented in the University and are, indeed, congested, but we have not shrunk from the obvious remedy, which the University and external friends have never withheld; our laboratories are being rapidly extended, and when the demand for extension ceases we shall recognize that the time has arrived for younger men with fresher minds to assume control. . . . For our part we welcome the presence of women in our laboratories on the ground that residence in the University is intended to fit the rising generation to take its proper place in the outside world, where, to an ever-increasing extent, men and women are being called upon to work harmoniously side by side in every department of human affairs.'

Rutherford's sense of humour peeps out.

'For better or for worse, women are often endowed with such a degree of intelligence as enables them to contribute substantially to progress in the various branches of learning; at the present stage in world affairs we can afford less than ever before to neglect the training and cultivation of all the young intelligence available.

'For this reason no less than for elementary justice and

expediency, we consider women should be admitted to degrees and to representation in our University. . . . Our friends among the opposition seem to forget that every broadening of University interest—the abolition of the disabilities of Nonconformists and the restrictions concerning the marriage of College Fellows, the provision of teaching and research facilities in science—has been the starting-point for rapid extensions in the usefulness of the University.

'We write these lines in hope of inducing some, so dazzled by the glories of Cambridge that they foresee no future greater than the past, to reflect that there is a great world outside for whose needs we have to cater, and to join with the supporters . . . in their determination to fill those needs in even greater measure than before.

'We cannot afford to retain women seen but not recognized in this University. . . .'

'Signed :

'Ernest Rutherford, Cavendish Professor of Physics.

'William J. Pope, Professor of Chemistry.'

On 30 April 1936 Lord Baldwin (then Mr. Stanley), Prime Minister, received in his capacity as Chancellor of the University of Cambridge the following letter :

'LICHEY GROVE,
'Near BROMSGROVE,
'29 *April* 1936.

'DEAR MR. BALDWIN,

'I have, for several years, been watching the very valuable work done by Lord Rutherford and his colleagues at Cambridge in the realm of scientific research, and knowing that as Chancellor you are keenly interested in obtaining sufficient funds with which to build, equip, and endow, a very much needed addition to the present resources, I shall be very pleased to present securities to the value of approximately £250,000 for this purpose.

'I am,
'Yours sincerely,
'H. AUSTIN.'

Came the reply :

' 10 Downing Street, S.W.1.
' 30 *April* 1936.

' Dear Sir Herbert,

' As Chancellor of the University of Cambridge, I gratefully accept on behalf of the University your most generous offer of £250,000 towards the extension and further endowment of the Cavendish Laboratory.

' There can be no greater encouragement to the men who devote themselves to scientific research than to feel that their work is appreciated by those engaged in industry, the progress and development of whose businesses depend so much on the laboratories of our country. Your noble gift will be invaluable at this time to Cambridge, and the benefits arising from its applications will be available for the civilized world.

' Yours very sincerely,
' Stanley Baldwin.'

Rutherford said on the same day : " I am very much gratified at the very generous gift of Sir Herbert Austin and his recognition of the important work that has been done in the past by Sir J. J. Thomson and his colleagues at the Cavendish Laboratory. The donation will give us the opportunity of building a modern research laboratory and will also be of great value in helping to defray the large expenditure required on modern research in physics, which often involves the use of apparatus on a costly scale. The first use of the money will be to build a laboratory for the utilization of very high voltages, in order to carry out experiments on the transmutation of matter by high-speed particles and by radiation."

By such means did the laboratory now to be known as the Herbert Austin Laboratory come into being—as the result of the magnificent response of the donor to the appeal for funds issued in 1936. The schemes for the reconstruction of the old laboratory which had already been aided by the removal of the Engineering and Zoological laboratories to another part of Cambridge and the plans for the new building were being considered by Rutherford.

Unfortunately he was never to see the scheme fulfilled. That he would have become its Director is hardly to be doubted, but his death cut him off in the middle of a score of activities; he was destined never to plunge into the experiments he had planned and looked forward to in the new laboratory. Instead, for his successor, that great pioneer in the field of X-ray spectroscopy and crystallography, Professor W. L. Bragg, F.R.S., he 'leaves a goodly heritage and a difficult task.'

CHAPTER XXIV

THE SUDDEN END

On Friday, 15 October 1937, Rutherford was suddenly taken ill at his home, Newnham Cottage, and was rushed to a nursing-home in Cambridge, where on the same night he underwent an abdominal operation. From this he appeared to make so good a recovery that it was planned to perform a further necessary operation on the following Monday.

On that day he had a severe relapse. A specialist was called in, Lady Rutherford sat by his bedside, anxiety but no alarm as yet was felt. On the Tuesday afternoon a bulletin was issued stating that Rutherford had passed a restful day, but that his condition was still giving rise to great anxiety. A few hours later Rutherford died in his wife's arms.

Thus did he leave human haunts to join his immortal predecessors, leaving behind him a sense of irreparable loss. The blow stunned his countless friends, it shocked the scientific world. The most important scientific personage of the times had been suddenly, without warning, taken from our midst at the age of sixty-six. 'A great and sudden sadness has fallen on the University through the death of its greatest physicist,' said the University correspondent of *The Times*. 'Lord Rutherford, since his return to Cambridge in 1919 . . . has been a living force in academic life and both intellectually and socially all things will be slower and weaker for want of his ubiquitous and enthusiastic energy.'

The thoughts of the world in general can be gauged from the newspaper headlines :

A Calamity to Science.
Pioneer in Modern Physics.
Greater than any Alchemist.
The Man Who Split the Atom.
Scientist Who Thrilled the World.
A Loss to the World.

Just as Herschel threw open the stellar universe for the astronomer, so Rutherford disclosed that infinitely small universe, the atom. " The whole history of the new alchemy . . . may be written in terms of Rutherford's work," said Professor E. N. da C. Anrade. Then, when he was about to have command of new and far more powerful apparatus he was taken away. It was, as Sir J. J. Thomson said, one of the greatest tragedies in the history of science.

Men of science throughout the world felt the tragedy deeply.

Said Stefan Meyer, of the Institute of Radium Research, Vienna :

" The world is poorer through the passing away of its leader in radio-activity and nuclear physics, Lord Rutherford, who was a unique personality, and what every single one of us has lost scientifically and personally is impossible to say in words. . . . I saw Lord Rutherford for the last time in 1932 in full vitality in Münster where the whole session of the Bunsen Gesellschaft was under the spell of his personality. In the following year he received my daughter and son in the kindliest manner, in Cambridge, in spite of the numerous claims on his time, and gave them many proofs of his friendly feelings. Whoever came into close contact with him will cherish the memory of how he attracted all, not only through his surpassing scientific greatness, but also through his human kindness and personal charm."

In a similar way does Professor A. Norman Shaw of the McGill University express himself.

" Old friends and pupils of Rutherford have memories even more deeply cherished than the recollections of his work itself. His lively humour, boyish zeal, and kindly human interest in the affairs of those around him, his untiring help in time of need, that remarkable driving ability by which he could obtain almost incessant work willingly given,

his uncanny and unerring instinct for the next best step, his hatred of pretence and untested generalization, his outspoken frankness, his uniform fair dealing, his capacity to pick able men and later place them in their life's work, his friendliness and approachability, his dominating voice and personality when deeply stirred—these attributes and more will be recalled as hall-marks of one man, Ernest Rutherford. In our lifetime we shall not see his like again."

Professor L. Wertenstein of the Free University of Poland:

"Rutherford has left us, but he survives in the hearts of all students of radio-activity and nuclear physics throughout the world. We mourn him, but our eyes are turned on those who are most deeply affected. While assuring them of our sympathy, we feel that the great inheritance is in good hands."

Professor Fermi of the University of Rome:

"The unexpected news . . . reached me at Bologna, when I was taking part in a meeting for the bicentennial celebrations of Galvani's birth. A large group of physicists from all nations were assembled there, and it was quite apparent how deeply everybody felt the loss that science had suffered, by the passing away of a man whose efforts had opened up to physics one of the widest and yet unfathomable fields of investigation. . . . Lord Rutherford will be remembered in the history of science not only on account of his personal contributions, but also as a teacher, in the highest meaning of this word. . . ."

Dr. Peter Kapitza, of the Institute of Physical Problems, Moscow:

"The death of Lord Rutherford is unanimously deplored by all men of science, but especially is it felt by his numerous pupils. . . . In the history of science, it is difficult to find another case when an individual scientist has had such great influence on the development of science. . . . I cannot think of any country from which young research people did not come at some time to work in his laboratory. . . . During my own time in Cambridge I can remember students working in the Cavendish not only from Great Britain and the Dominions, but also from the United States, Chile, China, Czechoslovakia, Denmark, France, Holland, Germany, India, Italy, Japan, Norway, Poland, the Soviet

Union, Switzerland, and other countries. Most of them now occupy professorial chairs, and some of them have gained an international reputation. I am certain that in all these countries there will be men of science who will sincerely mourn Rutherford's death not only as the greatest research physicist since Faraday, but even more deeply as their teacher and friend."

Professor Eve, a lifelong close friend of Lord Rutherford, and his successor in the professorial chair at Montreal:

"Much as we deplore the death of Rutherford while still at the peak of his powers, much as we anticipated a rich harvest from the recent improved facilities at the Cavendish, much as we miss and shall continue to miss his crystal-clear expositions, and yet more his friendly and delightful personality, yet who would have wished to have seen that bright intelligence wane or gradually fade? He was always a charming blend of boy, man, and genius, and it may still be true that those whom the gods love die young."

Dr. Chadwick:

". . . . He knew his worth, but he was and remained, amidst his many honours, innate and modest . . . he himself never presumed on his reputation or position. He treated his students, even the most junior, as brother workers in the same fields. . . . These virtues with his large, generous nature and this robust common sense endeared him to all his students. All over the world workers in radio-activity, nuclear physics, and allied subjects regarded Rutherford as the great authority . . . but we, his students, bore him also a very deep affection. The world mourns the death of a great scientist, but we have lost our friend, our counsellor, our staff and our leader."

Professor F. Soddy:

"Rutherford's death removes from science the most outstanding personality of the age . . . he was able to vitalize any public gathering and make it happier merely for his coming. . . . In the last letter I had from him, . . . he told me . . . he was feeling very fit and well, and able to hold his job down. The Fates have otherwise decreed. He reached, perhaps even did not quite reach, the summit of his powers, but for him there was to be no slow and inevitable decline."

Professor Niels Bohr of the University of Copenhagen :

" . . . the life of one of the greatest men who ever worked in science has come to an end. . . . but we may say of him as has been said of Galileo, that he left science in quite a different state from that in which he found it. His achievements are indeed so great that, at a gathering of physicists like the one here assembled in honour of Galvani, where recent progress in our science is discussed, they provide the background of almost every word that is spoken. . . . Rutherford passed away at the height of his activity, which is the fate his best friends would have wished for him, but just on account of this he will be missed more, perhaps, than any scientific worker has been missed before . . . together with the feeling of irreparable loss, the thought of him will always be to us an invaluable source of encouragement and fortitude."

Sir William Bragg, President of the Royal Society :

" In every place where learning is honoured there will be sadness and a sense of heavy loss."

Professor Chadwick at Glasgow on the day of Rutherford's death :

" The greatest experimentalist since Faraday. . . . Though he had made discoveries of which any man might be proud, Lord Rutherford was, in spite of his obvious self-confidence and self-reliance, one of the most modest of men."

Sir Thomas Holland :

" . . . he was a man of genius who might suitably be placed in the group headed by Sir Isaac Newton, because he discovered a new world, not by accident or lucky guess, but by working on strictly scientific lines, building on previously established physical bases . . . his infectious energy and boyish spirit seemed always like fresh air wherever he went, for he never sought honours or thought of financial reward. He was just happily devoted to science."

The following telegram was sent to the Government of New Zealand : ' His Majesty's Government in the United Kingdom join with His Majesty's Government in New Zealand in mourning the loss which the whole scientific world has sustained by the death of Lord Rutherford of Nelson. His brilliant researches have opened the door to the new discoveries which will assure him a place in history as one of the founders of modern physics.'

In the Parliament House the Prime Minister of New Zealand said: "I feel sure that all the people of New Zealand will join with me in expressing regret at the death of Lord Rutherford of Nelson in his sixty-sixth year. . . . He was foremost among New Zealand scholars and was not the least of the world's leading scientists. It would be foolish of me, as it also would for many others, to pretend any claim to knowledge of science in which the distinguished New Zealander won fame for himself and for his country. We knew him first as Ernest Rutherford and watched his wonderful career overseas with interest and proud appreciation. The whole world of science and scholarship came to admire him as Lord Rutherford, O.M., of Nelson, New Zealand, a brilliant professor of physics at Cambridge University, and a master of research in radio-activity.

"Many British and foreign universities honoured him with distinctive degrees, and the British nation through its King conferred its highest honour—the Order of Merit. These rewards are not given lightly in the exacting sphere in which the late Lord Rutherford won a great prominence, and we can all be sure that he deserved them. His life and work should be an inspiration to New Zealanders in their quest for the best in scholarship and in science. The people of New Zealand will cherish his memory and the fine record of his achievements."

Great as is the sense of loss expressed in these few of the scores of tributes paid by men in science and politics throughout the world, the greatest was felt by that person who, unobtrusively and gently, helped him ceaselessly, understanding him to the full, doing much of his private work, and receiving the full measure of his great companionship—Lady Rutherford.

On the occasion of one of his discoveries Professor Chadwick said to him: "You are a lucky man—always on the crest of the wave." To which Rutherford laughingly replied: "Well, I made the wave, didn't I?" adding soberly, "at least, to some extent."

"Truly his wave went with him," said Professor Chadwick, "wherever he went, a fine wave, lit by the sunbeams, for he had the three precious gifts of the poet, deep insight, powerful imagination, and a profound love of the truth

He was always a 'charming blend of boy and man and genius.'"

It was decided that Rutherford should be interred in Westminster Abbey. Lady Rutherford concurred. His ashes were laid in the nave of the Abbey on 25 October 1937 in the presence of a large gathering of eminent men from all walks of life. 'The honour thus accorded him,' said *Nature*, 'is fitting recognition of the place he held among his fellows, and the memorable service at his burial, in its simplicity, beauty, and dignity, was in keeping with the passing of a man of singleness of purpose, whose life had been devoted to unravelling the secrets of Nature.'

In this quiet, sincere manner his ashes were placed near the remains of Newton, Kelvin, Darwin, and Sir John Herschel. 'Another link was forged binding the Empire together, for Rutherford was the first man of science born in an overseas dominion to be buried in the Abbey.'

Among those present were:

Lord Fortescue, representing the King.
Mr. G. P. Humphreys-Davis, representing the Prime Minister.
Mr. Vernon Harington, representing the Lord Chancellor.
Lord Halifax, representing Lord Swinton.
Sir Samuel Hoare, representing Sir Thomas Inskip.
Earl Baldwin, representing the late Mr. Ramsay MacDonald.
Rear-Admiral A. Bromley, representing the Secretary of State for Dominion Affairs and Admiral of the Fleet.
Lord Chatfield, representing the Admiralty.

The ten pall-bearers were:

The High Commissioner of New Zealand.
Professor H. R. Dean, Vice-Chancellor of the University of Cambridge.
Lord Dawson of Penn, President of the Royal College of Physicians.
Sir Edward Poulton, President of the British Association.
Sir William Bragg, President of the Royal Society.
Professor A. S. Eve, representing McGill University.
Professor E. D. Adrian, representing Trinity College, Cambridge.
Sir Frank Smith, representing Department of Scientific and Industrial Research.

Professor W. L. Bragg, representing University of Manchester.
Sir George Lee, President of Institution of Electrical Engineers.

The service began with the singing of the sentences 'I am the resurrection and the life . . .' as the coffin containing the urn was borne slowly through the nave and choir to the bier placed in front of the sanctuary and beneath the lantern.

The 23rd Psalm was sung, the reading of Ecclesiasticus xliv, 1–14, and the hymns 'The King of Love my Shepherd is' and 'Praise my soul, the King of Heaven' finally died away.

Then the coffin was carried back to the nave and the sub-dean, Canon V. F. Storr, conducted the committal service, and pronounced the blessing. The service was brought to an end by the playing of Harwood's 'Requiem Aeternam.' Then, after the departure of the chief mourners the general public filed past that flower-strewn spot that will ever be Rutherford's, paying their last homage. It was a simple service. Not a word was said concerning Rutherford's attainments or distinctions.

His ashes lie beneath a simple slab in a goodly company.

Several proposals have been put forward as to the form of memorial most suited to Rutherford's personality. The best would be, perhaps, a travelling scholarship, enabling students to visit research laboratories of the Dominions and vice versa, and foster good will in the Empire which Rutherford loved so much.

Lord Rutherford, O.M., F.R.S., will for ever be remembered simply as Rutherford.

No one can fear that his name will never fade. It is amongst the immortals and his monument is already fashioned—his life's work.

In the words of the Sub-Dean of Westminster: "We thank Thee for the life and works of Ernest our brother."

EPILOGUE

THE JUBILEE OF THE INDIAN SCIENCE CONGRESS

BEFORE 1900 Science in India was confined almost exclusively to the large-scale services maintained by the Government, such as the Geological Survey, the Botanical Survey, and the Department of Agriculture and Meteorology. The researches of note were carried on by these services and to no great extent by the universities.

However, a few enthusiasts eventually got together and formed the Indian Science Congress in order that isolated scientists could get together annually at a meeting modelled on the lines of the British Association for the Advancement of Science.

After many months of planning it was at last arranged that representatives of the British Association should visit India. The chief difficulty being that the visit could only take place in the cool weather between November and February, i.e. during the British academic year, an inconvenient time. However, it was overcome. Rutherford was to attend. Then the Indian Congress suffered the cruel blow of Rutherford's sudden death.

He had, however, prepared his address about two months before his fatal illness, and Sir James Jeans, being chosen to take Rutherford's place, read this address to the Congress. Though they could not have the one and only Rutherford, they had a most prominent man whose work and writings have brought him fame and affection in all parts of the world.

Sir James prefaced the reading with a tribute to " one of the greatest scientists of all time."

In the address Rutherford commented on the growth of the Indian Science Congress, pointing out that in 1914 a report of the proceedings occupied six pages, while in 1928

it occupied 420 pages. Sketching out the needs of the Indian Empire in science and industry, he said: "The utilization of science implies, moreover, a planned scheme of research. Here the experience of some of the Overseas Dominions may prove of service to India. In Canada and in Australia there are State and Provincial Governments as well as a Federal Government, and in both cases it has been found expedient that the research organizations of the country should be truly national and responsible to the Federal Government alone.

"Even in an Empire the size of India, whose resources and needs of various provinces are widely different, it would seem that centralized organization of research is the only way of avoiding waste of money and effort. The detailed planning of research must be in the hands of those with the necessary specialized knowledge, and they must be able to act without suspicion of political or racial influence."

A singular feature of the Indian Science Congress Association is the complete absence of racial or communal strife, a striking tribute to those who realize that science should have no boundaries of race or politics, and in commenting on this Rutherford complimented the Association's officers and mentioned the great services rendered to it by Mr. J. van Manen, the secretary of the Royal Asiatic Society.

The latter part of Rutherford's address was devoted to a survey of the latest developments in his work and the outlook for the future. He said: "I have so far spoken of the importance of science as a factor in national development, but before concluding my address I would like to refer to some investigations in pure science in which I have been personally much interested. I refer to the successful attack on the age-old problem of the transmutation of matter which in recent years has attracted so much attention from physicists throughout the world."

Referring to the discovery of radio-active uranium in 1896, he said: "We had thus been given a vision of a new and startling subatomic world where atoms break up spontaneously with an enormous release of energy."

He spoke of the developments in the method of counting particles. "The electrical counter . . . has now reached such a stage of perfection that we are able to count

automatically individual fast particles like alpha-particles and protons, even though they enter the detecting chamber at a rate as fast as 10,000 per minute.

" It is to be emphasized that progress in scientific discovery is greatly influenced by the development of new technical methods and new devices for measurement. With the growing complexity of science the development of scientific technique is of ever-increasing importance for the advance of knowledge."

Considering the relations between the neutron and proton, he said : " We are still uncertain of the exact relation, if any. The neutron appears to be slightly more massive than the proton, but it is generally believed, although no definite proof is available, that the proton and neutron within a nucleus are naturally convertible under certain conditions. For example, the change of a neutron into a proton gives rise to a free negative electron. In this way it appears possible to account for the observed fact that either positive or negative electrons are emitted by a large group of radio-active elements. . . ."

He paid his last tribute to the particle to whose energy his own has already been compared.

" It is of interest to note," he said, " what an important part the alpha-particle, which is in itself a product of transformation of natural radio-active bodies, has played in the growth of our knowledge of artificial transformation. It is to be remembered, too, that our main source of neutrons for experimental purposes is provided by the bombardment of beryllium with alpha-particles."

After describing the modern methods of transmutation, he said : " It may well be that in the course of time . . . artificial radio-active elements may prove a useful substitute for radium in therapeutic work.

" Rapid progress has been made, but much still remains to be done before we can hope to understand the detailed structure and stability of different forms of atomic nuclei and the origin of the elements."

On the future progress of science, he said : " . . . as science progresses, important problems arise which can only be solved by the use of large powers and complicated apparatus, requiring the attention of a team of research

workers. If rapid progress is to be made, such a team is likely to be a feature of the more elaborate researches in the future. Fortunately there is plenty of scope for the individual research workers in many experiments of a simple kind.

"The science of physics now covers such a vast field that it is impossible for any laboratory to provide up-to-date facilities for research in more than a few of its branches. There is a growing tendency to-day to specialize in those particular branches of science in which they are most interested or specially equipped. Such a division of the field of research amongst a number of universities has certain advantages provided that this subdivision is not carried too far. In general, the university should be left free as far as possible to develop their own lines of research and encouraged to train young investigators, for it cannot be doubted that vigorous schools of research in pure science are vital to any nation if it wishes to develop effectively the application of science whether to agriculture, industry, or medicine. Since investigations in modern science are sometimes costly and often require the use of expensive apparatus and large-scale collaboration it is obviously essential that adequate funds should be available to the universities to cover the cost of such researches.

"In this brief survey I have tried to outline the contributions to scientific knowledge made in India, and the need of the immediate future in science is to play its part in national welfare. While the study of modern science in India is comparatively recent and naturally much influenced by Western ideas, it is well to recall that India in ancient days was the home of a flourishing indigenous science, which in some respects was in advance of the rest of the world at that time. The study of ancient writings discovered in recent years has revealed the extent and variety of these scientific contributions, which notably advanced the study of arithmetic and geometry. The researches of Sir Prafulla Ray have also brought to light the important advances made in metallurgy and chemistry. May we only hope that this national aptitude for experimental and abstract science, shown so long ago, is still characteristic of the Indian peoples, and that in the days to come India will again become the

home of science, not only as a form of intellectual activity, but also as a means of furthering the progress of her peoples."

It is to be hoped that Rutherford's wishes regarding contact between India and Great Britain will be maintained and that the scientists of these two countries will be able to pay alternate visits to one another.

Rutherford saw the importance of this kind of contact and considered that the British Association could do excellent work by sending delegations to outlying parts of the British commonwealth of nations. An editorial in *Nature* made the admirable suggestion that 'the Association could raise no more enduring monument to the memory of the great physicist who has so recently left us, than by the institution of a series of delegations to be known for all time as the "Rutherford Delegations," and to be charged with the duty of fostering the unity of all the Empire by carrying the lamp of science and learning to her uttermost dependencies.'

One may be, perhaps, permitted to express the hope that science will be able to play her part in drawing closer together not only the nations of the British Empire but the nations of the world. Even in the most troubled moments of the past decade there have been harmonious relations between the scientists of countries politically at variance. May the day come when the nations can work together for the advancement of mankind and the increase of knowledge as harmoniously as did their representatives grouped together at Manchester and Cambridge under the inspired leadership of Baron Rutherford of Nelson and Cambridge, O.M., F.R.S.

INDEX

Epsom and the Dorlings

by THE REV. E. E. DORLING, M.A., F.S.A.

THE first Dorling settled almost accidentally in Epsom at the beginning of the nineteenth century. Since that time he and his descendants have become the most famous people there, for they have done more than anyone else to maintain and increase the popularity of the race-course, and particularly that most famous of all horse-races—the Derby.

The Dorlings have been the Clerks of the Course, and the General Managers and Chairmen of the Epsom Grand Stand Association. From these prominent positions they have seen all the dramas of Epsom and have come in contact with every important personage frequenting the race-meetings.

From archives, family records and minute books to which only he has access, Mr. Dorling has traced the growth of the Race-course, and tells how the rascally Charles Bluck was outwitted in his attempt to gain control of the Grand Stand ; how Henry Dorling, the author's grandfather, became the lessee of the Grand Stand and, with the help of such famous men as Lord George Bentinck and Charles Dickens, restored Epsom's prestige.

There are tales, too, of the Dorling family, of Henry Dorling and his 21 children, one of whom became Mrs. Beeton, the writer of the cookery book ; of Henry Mayson Dorling, a "character" if ever there was one ; and of old William Dorling and his "Correct Race Card". There are anecdotes of Kings and Princes who have visited the race-meetings, stories of the famous Derby Day luncheons, tales of jockeys and trainers and well-known owners. A chapter, too, deals with the most famous horses that have ever run at Epsom.

This book is outstanding among racing reminiscences and illustrated by old prints and photographs which Mr. Dorling alone can supply. It will appeal to enthusiast and layman alike.

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"... *of Caviare and Kings*"

by VICTOR QUINTO

Born in Piedmont, Italy, forty-seven years ago, the youngest of thirteen children, Signor Victor, one of the world's greatest restaurateurs, has lived to the full. Still young, his life story makes a glowing pattern of experience.

The world of leisure and gracious living has disintegrated, but floating on the top of polyglot Society there remains a select coterie of gourmets, whose super-civilisation makes them harder taskmasters than the most slave-driving of industrialists. They pay well for their delicate pleasures, yet they must have the best, and only the best will do. To cater to the tastes of these elegant dictators of the restaurant the soul and talent of the true artist is required. In that sense of the word, Signor Quinto is an artist.

Signor Quinto's life has been dedicated to serving the discerning. He was apprenticed to a hard school, and it was many years before he managed even to gain a foothold on the heights of the *bons viveurs*. From scullery to kitchen, from being a mere waiter to being the *Maître*, he had to fight his way, but the spirit and the instinct were there and the great Quinto was indomitable. His fight for recognition took him all over the world till at last he reached his goal and found his gastronomic Arcadia, fittingly enough, on the Côte d'Azur.

Signor Quinto's early days in Europe and America equipped him with a deep understanding of human nature, and it is this trait, combined with his incomparable contact with world celebrities, that makes "... OF CAVIARE AND KINGS" so gay, so richly flavoured with the spice of high life.

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Spies To-day

by MAJOR A. G. WADE, M.C.

Major Wade, whose first book, *Counterspy*, told the story of his amazing adventures in England and Salonika checking the work of the German spies who tried to undermine the national effort of this country to win the war, has completed a searching

inquiry into the work of the spy to-day in times of peace.

Major Wade argues that it is in time of peace that the agent of a foreign power had his greatest opportunity to work underground for his country; that the spy achieves his greatest results in the organization of subversive propaganda, the creation of opportunities for sabotage, and the sowing of the seeds of industrial unrest.

He is convinced, and tells many stories which prove his arguments, that the spy to-day is more concerned with an attack on the morale of a country than he is with the discovery of armament secrets.

The author, who has kept in close contact with the secret service ever since the last war and has watched the growth throughout the country of the political influence of agents of foreign countries, has many stories to tell of the way in which during the last few years the British have allowed themselves to be "bamboozled", as he describes it, into acting in a way which has handicapped the industrial development of this country, on which its arms and therefore its security depend. He reinforces these stories by anecdotes of the wars in Spain and China which illustrate not only the theory but also the practice in time of war of modern espionage.

By the author of *Counterspy*

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The Wanton Queen

THE INTIMATE STORY OF QUEEN CAROLINE

by E. E. P. TISDALL

THE favourite childhood game of Caroline of Brunswick-Wolfenbuttel was to play at Kings and Queens; and when she came to London in 1795 to marry the Prince of Wales (afterwards George IV), it seemed that she would find the *Crown* of her dreams.

But the only *crown* which came to Queen Caroline was a *cardboard crown* (valued by a contemporary at eighteenpence !)

It was carried before her coffin on a worn, second-hand cotton-velvet cushion, when in 1821 the most fantastic funeral procession London has ever seen fought its way from Hammersmith to Fleet Street. In ten hours of bloodshed and riot, leaving corpses by the way, to the sound of hymns, oaths, pistol shots and splintering barricades, this trifling distance was achieved!

London turned into a madhouse and Britain tottered on the edge of civil war for the sake of this gay Queen, who stood boldly at the Bar of the House of Lords charged with adultery. Even the Guards were threatening disloyalty to the King in their enthusiasm for Caroline.

Caroline was beautiful, frolicsome and indiscreet, living a life of colour and romance, worthy of a best-selling novel. Her affair with the notorious *Baron Bartomolo Bergami* rang through Europe. But Britons refused to believe the scandalous news of the "ill-used" Caroline; poets even dubbed her Saint Carolina!

Historians have glossed over this extraordinary page of history, which Mr. Tisdall reconstructs from obscure diaries and forgotten memoirs, in the same vivid and intimate way in which he treated his remarkable life of "John Brown".

By the author of *Queen Victoria's John Brown*, etc.

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The Royal Ladies of the Netherlands

QUEEN WILHELMINA AND PRINCESS JULIANA

by L. J. POWER

A FEW leagues away from the battle-fields of Europe lies the country of canals and windmills, governed by a spirited and popular Queen. This book tells the story of the family of Queen Wilhelmina of the Netherlands, who has been described as "the last man on a throne in Europe", the ruler who inherited Queenship from her mother Queen Emma, raised it to its present pinnacle and now is ready to hand it on to her daughter Juliana.

It is Queenship that typifies all that is best in Dutch life. Queen Wilhelmina is a flower lover in the country of tulips, an artist and patron in the country of Rubens and Rembrandt, and even a cyclist in a country of cyclists.

Queen Wilhelmina calmly went on painting when she sent a battleship to fetch President Kruger from South Africa when the Boer cause was lost. She quietly rode her bicycle around the streets of the Hague while she defied the Allies' demand to deliver up the ex-Kaiser. She was not afraid to rebuff Hitler when Nazi bluster tried to retain Prince "Benno" as a German National. "This is not a marriage of Holland and Germany, but a marriage of my daughter to the man she loves."

Modern Holland is closely linked with Britain. The future will demand even closer ties. Dutch Colonial possessions in the East Indies, dove-tailed into British territory, may yet form a bastion against Oriental expansion Australia-wards. British readers will enjoy the fascinating story of the Queen—and her daughter and son-in-law—who rules a contented country where Capital and Labour, Catholic and Protestant, dwell in harmony.

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Twenty Years under the Sea

by H. J. BRUCE

WITH A FOREWORD BY ADMIRAL SIR R. Y. TYRWHITT, BART., G.C.B., D.S.O., D.C.L.

THE life of the deep-sea diver is always surrounded by a halo of romance to the vast majority of us who have never explored the strange and unknown realms of the ocean depths, and here is an autobiography which is full of rapid action and continual thrills.

For twenty-two years Mr. Bruce served in the Navy as diver, which is quite a long time, but as one reads of his continuous string of adventures and misadventures it is difficult to imagine how he ever found time to eat and sleep.

There are, of course, the comparatively (for the diver) conventional fights with octopus and shark, but there are also many stranger incidents. There is, for instance, the case of

the abandoned suit of overalls lying on the ocean bed which suddenly arose before Mr. Bruce's horrified eyes and commenced to dance a solemn *pas seul ;* the search in an under-sea city of red coral for the Admiral's lost telescope ; an encounter with the trail of what may have been the sea-serpent ; a desperate fight with "CO2", and a dreadful experience when Mr. Bruce was almost engulfed by an under-sea bog.

Nor did the whole of Mr. Bruce's adventures take place under water, as exemplified by his strange fight in the dead of night with an enormous armadillo ; the epic of salving the coal from a blazing collier, and the escorting of the Sacred Carpet from Cairo to Jeddah.

It is doubtful whether any fictional work can equal this life-story of Mr. Bruce's for either thrills or laughs.

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The Death Treasure of the Khmers

by LANCE COLAM

In Macao, Portugal's tiny colony in China, Lance Colam met a half-caste French Cambodian. Under the influence of opium in one of the city's narcotic dens, the half-caste told the author the story of his finding the hidden treasure house of the Khmers, the vanished race whose civilization attained marvellous standards 800 years ago.

It appeared that a small body of priests had preserved the secret of this hiding-place through generations, and when the half-caste had accidentally come upon the spot he had immediately been marked down for death so that the secret might not be divulged.

Making his way to Angkor, Lance Colam had to journey six days north into the thick jungle before he came to the spot where the treasure lay hidden, and near which the half-caste's daughter was kept prisoner. He was just in time to witness a death ceremony and to see the daughter plunge a dagger into herself. By pretending to be a butterfly collector he was able to stay in the locality, although the priests were suspicious. With the help of a Chinese guide, the author

managed to find the hidden underground chamber in which the vast treasures of the Khmers were stored. But he was given no time to take anything, for the guardian of the treasure suddenly appeared and took the most effective protection measures by liberating a twenty-foot python, which compelled him to flee for his life.

He was able, however, to rescue the sister of the girl who had been killed, and brought her back from confinement to civilization.

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by GEORGE HAMILTON

EVER since Robert Louis Stevenson wrote his *Treasure Island*, the subject of treasure hunts of all kinds, both real and imaginary, has been dear to the hearts of all readers.

This story cannot fail to catch the imagination and thrill the hearts of all who are susceptible to the lure and romance of Hidden Treasure.

As romantic and heart-stirring as any, this has the advantage of being true, also the additional thrill that the Treasure is still in existence and can be found by those who care or dare to seek it, barely concealed on its coral island in the South Seas.

Mr. Hamilton's stirring narrative tells how four desperadoes signed on board a schooner carrying the treasure, mutinied, murdered the skipper and crew, and buried the Treasure on a small atoll ; of how they all came to bad ends, until the only survivor, when dying, bestowed on Charles Edward Howe the original chart showing the whereabouts of the Treasure.

The author was attached to Mr. Howe's expedition as an expert diver, and his story is embellished by meetings with such well-known people as Zane Grey, Douglas Fairbanks, Senior, a glamorous native Princess, and the descendants of the *Bounty* mutineers.

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Portland Spy

by R. A. HAVARD

In all the stories that have been told of the work of the secret service during the war and of the parts played by the famous centres of service activity, very little has been mentioned of the important part taken by the naval patrol centred on Portland, which has been described as the "Gibraltar of the Channel."

Portland was the centre of the anti-submarine patrol and the home of the training of men for the "Q" ships and motor boats which were eventually to bring the German "U" boat campaign under control and make it possible for supplies of men and material and food to reach this country without interference. It was vital that the work should be kept secret and the mysteries are only now, 20 years after the war, being released for publication.

Mr. Havard, who was stationed at one of the great forts which protect the famous Breakwater, remembers Portland for the scares of espionage that were the constant worry of the authorities in charge and for the way in which even the veriest recruit to the defence of the harbour was liable to become the object of interest to a German agent. In his own particular experience he was twice made the target of the spy, and in one case in particular, the object of the admiration of a clever woman who thought he could provide her with information that would lead to the blowing up of the fort and the consequent blocking of the entrance into Portland Roads of all ships of the anti-submarine patrol.

This is the factual story of an important part of the last war told for the first time.

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Mystery, we often think, is only to be found in desolate places —in the dark ; yet in the populous and sunlit lands of the blue Mediterranean lie many amazing and insoluble mysteries.

Round its shores nations and empires have grown and crashed; even now the struggle continues. And as each passes it leaves its legacy of secrets. Phœnicia, Egypt, Carthage, Greece, Rome and Byzantium have all bequeathed a wealth of mystery. Uncanny beliefs and horrible rites are still to be found there. Strange people haunt the shores; modes of thought alien to the western mind hold sway around the Mid-land Sea.

Why have once fertile regions become desert or swamp? How can we explain "ghost-light", human-shaped stones, ruts of gigantic carts?

Great crimes have been committed by those shores and great miracles have been performed; ruthless poisonings and miraculous cures have startled mankind, but remained unexplained. Castles and dungeons have been the scenes of many known tragedies, but what secrets have the monasteries guarded so carefully throughout the centuries?

Mr. Glenne reminds us of many a strange story; of the myths, miracles and mysteries built around the powers of good and evil.

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Prince Ahmad of Egypt

by JAMES BLAND

PRINCE AHMAD SEIF-ED-DIN was fifty-six when his unhappy career was brought to a close by his death at Istanbul. Although the Prince, during a period of forty years, monopolised the headlines of the British Press on a number of occasions, few people realise that he spent a large portion of his life in England —behind the walls of a mental home. His troubles began in 1898 when, at the age of seventeen, he shot at and wounded his brother-in-law, later King Fuad of Egypt. His sister had complained that she was being ill-treated by her royal husband and, in a fit of rage, Prince Ahmad went to a fashionable club in Cairo, and, before an audience of distinguished politicians and diplomats, drew a revolver and fired, wounding Prince Fuad in the neck. Criminal proceedings followed and Prince Ahmad was charged with attempted murder, was fined £1,800 and sentenced to seven years' penal servitude. He began his

sentence as an ordinary prisoner but was later announced insane. He was transferred to a private English mental home, and for more than 25 years relatives and friends intrigued to secure his release. Then one day in the summer of 1925, the Prince disappeared. A hue and cry broke out, and it was discovered that the Prince had crossed to the Continent.

Prince Ahmad, while in England, was estimated to have an income of £200,000 a year. But his estates, said to be worth £4,000,000, were sequestrated. He attempted, in vain, to sue the British Government for this amount. In 1933 Prince Ahmad married a Turkish girl and settled in Istanbul.

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The Lost Legion

by GUSTAV BECVAR, M.C.

ONE of the most amazing yet practically unknown epics of the war was the march of 70,000 Czech soldiers across Russia, and over the plains of Siberia to Vladivostock. The efforts of these men altered the course of history, for, after the fall of the Tsarist regime and the utter collapse of the Russian armies, they were largely instrumental in preventing the Germans from tapping the vast food stores of Siberia.

Had the Germans secured these food supplies, they might have staved off internal disruption, and prolonged the war for many months.

With the rise of the Bolsheviks, the Czech legions were left alone, face to face with the might of the German and Austrian armies, and surrounded as well with hostile revolutionary Russian troops. The only thing to do was to fight their way to Vladivostock, and go home by sea.

The thrilling story of this amazing struggle, which lasted until 1920, is here related by one of the legionaries who, incidentally, was the last man, other than Bolsheviks, to talk to General Kolchak. In this book he tells many hitherto unpublished facts and stories about the ill-fated General. Mr. Becvar possesses many war decorations, but it is interesting to note that he received his M.C. from the hands of General Knox, who was in command of the British troops in Siberia.

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Princess Louise—Duchess of Argyll

by DAVID DUFF

On March 18th, 1848, Princess Louise Caroline Alberta, sixth child of Queen Victoria, was born. This day marked the beginning of a long, exciting life that was to shatter all the conventions of Victorian womanhood.

Princess Louise early displayed artistic ability. This was at first unfortunate, for in those days artists were regarded as strange folk, and "Bohemians" were not encouraged in Court circles. That her mother was reconciled to, and even approved of, this gift of her daughter's, is proved by the fact that Queen Victoria unveiled a statue of herself executed by Her Royal Highness the Princess Louise.

Princess Louise was the first Princess of the Blood for many years to marry out of the royal circle. It was with reluctance that Queen Victoria gave her consent to her daughter's marriage with a commoner, the Marquis of Lorne, afterwards Duke of Argyll. In the hearts of the people, however, nothing could have been more romantic or satisfying than this perfect love-match.

Although she preserves an aura of Victorian dignity, Princess Louise has always been a modernist. She shocked her mother by her strong advocacy of "the rights of women" in an age when woman's place was in the home, and in the home alone. The path of royalty is straight and narrow, the course is well-defined, but the Princess derived considerable amusement from travelling the Continent incognito as "Mrs. Campbell".

Mr. Duff has had access to hitherto unpublished information about this "grand old lady", and presents his material in the most attractive form.

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JOINING the Northumberland Fusiliers as a boy, John Fraser went out to India and spent many years there. He has numerous stories to tell of army life there, not the least interesting of which concerns his friendship with Rudyard Kipling.

Stories of Kipling's adventures among the privates of John Fraser's regiment, whom he visited frequently while seeking colour for his soldier tales, are here told for the first time.

Another amusing story tells of his rescue of Lord Baden Powell from a gang of high-spirited soldiers who had not recognised the great man.

As a Beefeater, John Fraser spent 35 years in the Tower of London, that picturesque home of ceremonial. He has played an important part in many ceremonies, has lived in the house where Lady Jane Grey was imprisoned before her execution, and knows stories of spies imprisoned and executed in the Tower.

At the time of the Coronation John Fraser guarded the Regalia in the Jerusalem Tower of Westminster Abbey. He has conducted many distinguished visitors round the Tower, including the Princess Royal.

His account of the life of the little community living in the Tower is very interesting, and throws much new light on one of the oldest and most famous of English institutions.

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Son of a Dorset farmer, educated at Hereford High School, and intended for politics, Mr. Hayter found the doubtful thrills of electioneering for his M.P. a poor substitute for his dreams of African jungles, cannibals, big-game hunting, and the call of the wild.

He successfully executed a commission to trap and bring to the Monkey Hill at the London Zoo from Abyssinia the largest number of baboons ever brought into this country. His experience of life in Abyssinia made him determined to return there, but he was first obliged to serve two years in the Palestine Police.

Back in Abyssinia, with lions, leopards, crocodiles, snakes, monkeys of the jungle, and natives as his sole companions, he tried his hand at hunting, gold prospecting, and exploring; he trekked many hundreds of miles over unknown mountains and through previously unpenetrated jungles in ancient Ethiopia.

Mr. Hayter has associated with lepers, and has found his friends among the most unlikely people. Outcasts taking refuge in Abyssinia were his companions, and they proved to be friends in need.

As a tale of hardship and peril, of hairbreadth escapes, thrills, and persistence in face of danger, this book promises to rival the already classic yarns of *Trader Horn*.

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HERE the author ranges the length and breadth of the world's most colourful continent, and the secrets he reveals of life behind the scenes in many hidden corners of the East will fascinate the imagination of any reader who has ever felt the lure of the strange world "East of Suez".

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The veil of purdah is drawn aside, affording fascinating glimpses of life in the harem and zenana; and the author has some illuminating things to say about the fate which awaits the white woman who allows herself to be blinded by

visions of Oriental "glamour" and luxury into becoming an inmate of one of these establishments.

Secret ceremonies in many Eastern lands; twentieth-century cannibals; Oriental pirates and their ways; secrets of Asia's headhunters; and thrilling stories of blood-feuds on the Border form further chapters of the book, which also offers some of the most amazing and picturesque details ever published of life in the palaces of India's ruling princes.

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LORD RUTHERFORD was recognised universally as the world's greatest scientist. But little is known of his work outside his startling discoveries, such as the constitution of the atom and his feat in splitting it.

The significance of his work and the firm foundations he built for the construction of our everyday wonders are understood by scientists alone. Little is known of Rutherford the man.

The book reveals both sides, the scientific and human. It shows him as a man of simple tastes, enjoying a game of golf, all his life retaining the bluff Colonial geniality that he inherited from his New Zealand parents. It describes his life as a boy, as a student in Cambridge, as a professor in Montreal, Manchester, London, and finally Cambridge again.

The story of his achievements and their value to humanity is translated from the loftiest scientific language to that of the ordinary man without losing its meaning.

This book gives a living and fascinating story of the world's greatest modern scientist.

The author is himself a scientist, and was known to Lord Rutherford, and is one of his greatest admirers.

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Medical Memories

by COLONEL N. J. C. RUTHERFORD, D.S.O., M.B., R.A.M.C.

THE author, a retired Army surgeon, has practised the profession of medicine in many lands, including the Far East and South Africa, and he also accompanied the Swiss Commission that visited all the prisoner of war camps, including Donington Hall, during the Great War.

Whilst on a recent visit to the Cape he became interested in that remarkable personality, Doctor James Barry, who served as an Army surgeon from 1815 to 1865, and reached the rank of Inspector-General of the Army Medical Service. Only at death was this distinguished officer found to be a woman, and she is the first known instance of a woman acquiring a medical degree. How was it possible for her to conceal the secret of her sex throughout her somewhat stormy Army career ?

The author deals with his conception of this intriguing problem and with other wide and varied experiences of his own in a style which is both lively and entertaining, and his account of the duel which Doctor Barry fought at the Cape with a young officer who considered himself aggrieved at her attentions to one of the reigning beauties of the day certainly does not lack a delightfully humorous aspect.

By the author of *Soldiering with a Stethoscope*

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Japan

REMINISCENCES AND REALITIES

by LESLIE W. JOHNS

THERE are more conflicting opinions about Japan than any other country ; some praise her for her amazing progress to modernity from medievalism, while others revile her for her disregard of international law and her repeated attacks upon China.

The author has lived in Japan for the greater part of his life, and has also lived in other parts of the world long enough to be able to regard Japan with an unbiased eye ; the Japanese are shown as they appear to a man who has lived among them for nearly twenty years.